REGIONAL SETTING OF STRUCTURALLY HOSTED GOLD MINERALIZATION IN THE MUDGEE-GULGONG DISTRICT N.S.W.

by

Joffre

JOHN J. WATKINS

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the candidates knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text

ABSTRACT

The Mudgee-Gulgong district is located within the exposed northeastern margin of the Lachlan Fold Belt in New South Wales. The district was an important gold mining centre in the 1800's and produced up to 1 million ounces of gold, mostly from deep leads. Re-mapping of the area has resulted in a major revision to the stratigraphy and structural knowledge of the area. Significant changes include the recognition of the formerly known Early Devonian Burranah Formation as a Late Ordovician volcanic unit with significant exploration potential for Au-Cu mineralization Also recognised is a Late Silurian shelf sequence with potential for Au-Cu and base metals overlying the Burranah Formation.

The Burranah Formation is a dominantly submarine, volcano-sedimentary succession with a complex internal stratigraphy. Two main lithofacies associations can be recognised on the magnetic images. A lower package, composed mostly of primary volcanic rocks and minor volcaniclastics is overlain by a package composed dominantly of volcaniclastics and sediments. Small elongate intrusive bodies occur throughout the sequence.

Structural interpretation of the area reveals one dominant D_2 deformation (Early Carboniferous) that produced meridional to northwest-trending folds, cleavage, thrust faults and oblique-slip faults. A zone of higher strain is developed within the Burranah Formation and is characterised by overturned, tight, F_2 folds and considerable shortening.

Mapping and interpretation of the area has been greatly assisted by the availability of high resolution gravity, magnetic and radiometric data. The interpretation of magnetic data has considerably enhanced the structural interpretation.

Volcanic and intrusive rocks of the Burranah Formation comprise a coherent calc-alkaline suite with a dominantly shoshonitic character. In MORB-normalized plots, they display patterns typical of many modern subduction-related volcanics with a marked depletion of Ta and Nb and similar or lower abundances of the heavy REE and Ti. Positive εNd values indicate a mantle source for the shoshonites with little or no crustal contamination.

Primary gold mineralization in the district occurs in veins and as disseminations in the structurally more competent rocks adjacent to faults and shear zones in the higher strain zone. Host rocks are generally intrusive monzodiorites, diorites or coherent volcanics and range in age from Late Ordovician to Early Devonian. Sulphur and lead isotope data support a syndeformational model for mineralization with fluids and gold derived from the host rock sequence.

INTRODUCTION

Background

The study area is located about 280 kilometres northwest of Sydney between the towns of Mudgee and Gulgong in central New South Wales (Fig. 1). The area comprises a series of north-south striking hills and gently undulating low hill lands that are used for a variety of agricultural pursuits including sheep and cattle grazing and grape growing. The latter activities are restricted to the poorer quality soils developed on sedimentary sequences with gentle slopes.

The area lies within the Dubbo 1:250,000 geological sheet which is currently being re-mapped by the New South Wales Geological Survey as part of the National Geoscience Mapping Accord. The work undertaken in the study forms part of this regional mapping program and the results will be incorporated into the new Dubbo 1:250,000 geological map.

The Mudgee-Gulgong district was an important gold mining centre in the late1800's and Gulgong in particular was one of the richest deep lead gold areas in New South Wales. Official recorded production for the Gulgong area between 1870 and 1927 (Jones, 1940) was 555,205 ounces. However true production figures from the field are thought to be closer to 1 million ounces. Several reef mines were worked in the area, notably the Red Hill, Gulgong and Mariner mines, however the majority of the gold production (96%) was derived from the deep leads.

The Early Tertiary Gulgong deep leads are located principally to the south and southeast of the township of Gulgong and are, in part, capped by Tertiary basalts. The Gulgong Granite, located about 16 kilometres to the southeast of Gulgong, was historically thought to be the hard rock source for the Gulgong deep lead gold.

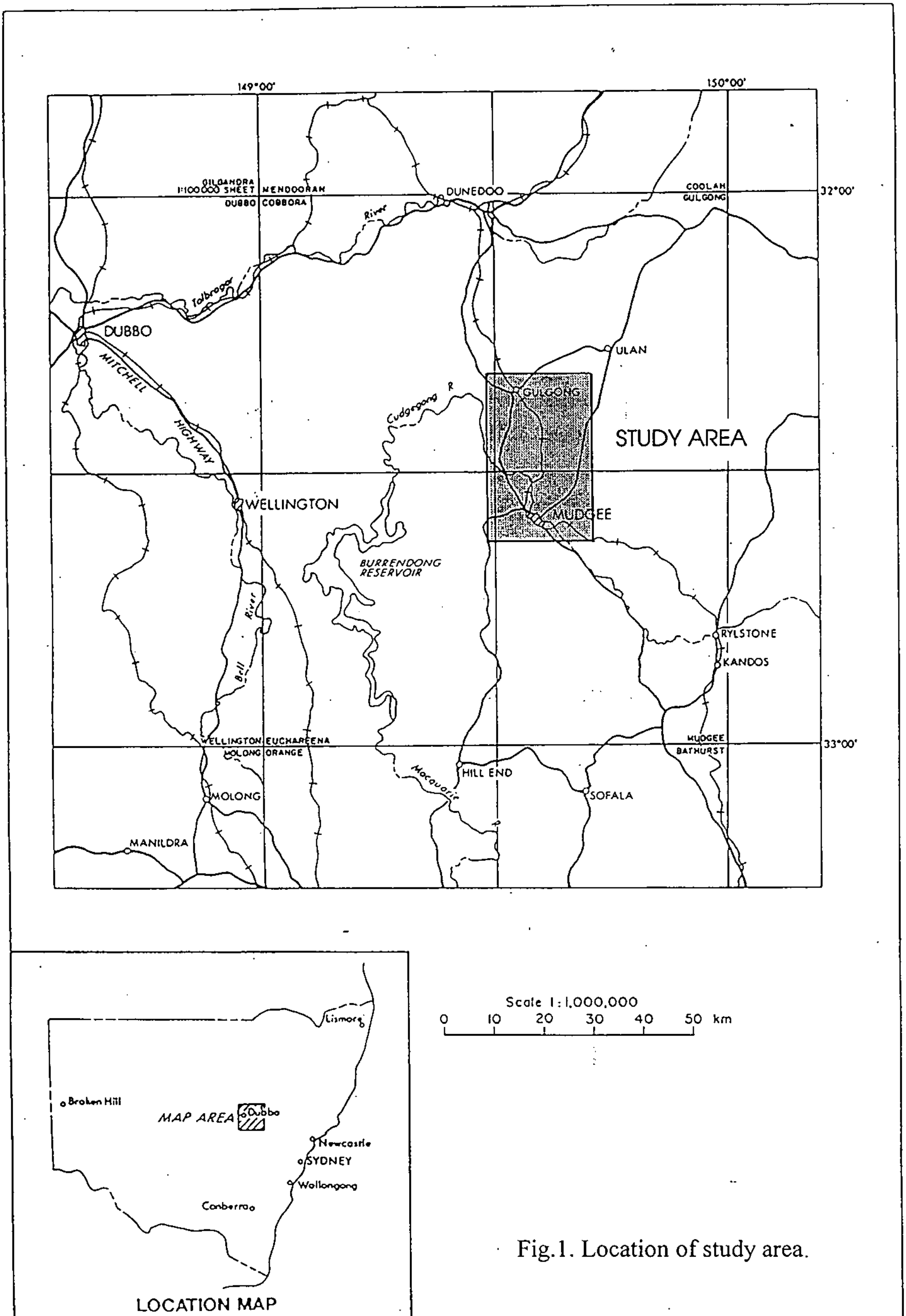


Fig.1. Location of study area.

Ground magnetic surveys over the deep leads conducted by Rayner (1940) showed that the deep leads drained north in a radial nature from the area to the south of Gulgong and not from the granite as previously thought. This area was later mapped by Offenberg et al., (1971) who showed it as an Early Devonian intermediate volcanic unit that was named the Burranah Formation.

Since the original mapping and compilation of the Dubbo 1:250,000 geological sheet by Offenberg et al. (1971), and a minor update by Matson (1973) for the metallogenic sheet, there has been little thesis work in this area and only minor exploration activity.

The Lachlan Fold Belt is currently the focus of a major exploration effort by mining companies searching for magmatically related copper and gold deposits. The main geological environment for this effort is large subvolcanic intrusive complexes associated with mantle-derived Ordovician shoshonitic volcanic rocks.

During the early stages of mapping, the Burranah Formation was found to be Late Ordovician in age. This was initially based on an interpretation of a bright red (high potassium) response on the radiometric image. The response also suggested the formation may be shoshonitic in character. Interest was heightened when a detailed inspection of limestone clasts from a debris flow unit within the Burranah Formation provided rare examples of several typically Late Ordovician corals. The debris flows in these instances are contemporaneous with the development of the volcanic pile. The significance of this finding clearly upgraded the prospectivity of the Burranah Formation and highlighted the need to further understand and characterise this unit and the nature of any mineralization.

Research Aims, Objectives and Methodology

Aims

The aim of this research project is to produce a new regional-scale geological and structural framework for the Mudgee-Gulgong district and a preliminary depositional model for the primary gold mineralization.

The study focuses on the Late Ordovician Burranah Formation. This unit is regarded as the most poorly understood, yet the most prospective and is therefore the subject of detailed mapping, geochemistry and mineralization studies.

Objectives

1. Produce a revised stratigraphy and detailed regional geological map of the Mudgee-Gulgong district.

2. Focus on the Burranah Formation and characterise its geological setting, its geochemical character and possible tectonic setting.

3. Review the structural history of the area with particular reference to the Burranah Formation.

4. Establish the nature and controls of the primary gold mineralization. Propose a preliminary genetic classification for each of these deposits and a depositional model for the district.

Methodology

Mapping of the area was carried out using 1:25 000 scale colour aerial photographs. The photographs were interpreted for areas of possible outcrop (elevated areas of residuum, colluvium or outcrop) which were followed up with detailed ground checking, particularly within the Burranah Formation and in areas of mineralization. Actual outcrop throughout the area is poor and averages about 20 to 30 per cent of the total area.

Mapping in the area was greatly assisted by enhanced computer images of airborne radiometric and magnetic data. Landsat TM data was evaluated but was found to be of little value due to the extent of cultivation and pasture improvement. Because of the poor outcrop, the structural framework for the area is based largely on an interpretation of the magnetic data with support from field observations.

Two series of maps were produced: a 1:50,000 scale fact map (Fig. 3,map pocket) and a 1:50,000 scale interpretation map (Fig. 4, map pocket). The interpretative map represents a synthesis of the geological data together with the results from the interpretation of radiometric and magnetic data sets. The interpretation map represents the first thorough synthesis of new geological and geophysical data for this comparatively poorly known area and represents a significant component of this research project. The new interpretation for this part of the Lachlan Fold Belt differs markedly from the existing published map (Matson, 1973).

REGIONAL GEOLOGICAL SETTING

TECTONIC SETTING

The Mudgee-Gulgong district is located in the exposed northeastern margin of the Lachlan Fold Belt in central New South Wales and occurs mostly within the Capertee Structural Zone of Scheibner (1993). The western part of the area falls within the Hill End Structural Zone and has outliers of Permian sediment from the Sydney Basin Zone (Fig. 2). Within the Capertee Zone, the Burranah Formation now forms the northernmost occurrence of the Late Ordovician Sofala-Rockley Volcanic Belt and is preserved along with elements of Late Silurian and Early Devonian shelf sequences. Carboniferous I-type granitoids intrude the Capertee Zone in the north and east of the area. Late Silurian turbidites comprise the basal unit of the Hill End Trough within the Hill End Zone.

The Late Ordovician volcanic units have been regarded as part of a single volcanic arc or series of arcs, possibly related to west-dipping subduction (Scheibner, 1974; Pemberton and Offler, 1985; Packham, 1987). However, Wyborn (1992) regarded these units as part of a mantle-derived igneous pile that were unrelated to Ordovician subduction.

From the Early Silurian until the Middle Devonian, the area probably occupied part of a backarc or intra-arc continental margin setting to the west of a west-dipping subduction zone located in the ancestral New England Orogen (Scheibner, 1989; Fergusson and Coney, 1992; Collins and Vernon, 1992). Extension in the eastern Lachlan Fold Belt created a series of meridionally-trending deep water basins or 'troughs' flanked by shallow marine to terrestrial platforms or 'highs' (Packham, 1960, 1969; Cas, 1983; Powell, 1984). The facies and palaeogeography of the Hill End Trough and its flanking volcanic margins (the Capertee and Molong Highs) during this time compare favourably with modern ensialic interarc or backarc basins, such as the southern Havre Trough in the Taupo Volcanic Zone north of New Zealand (Cas and Jones, 1979).

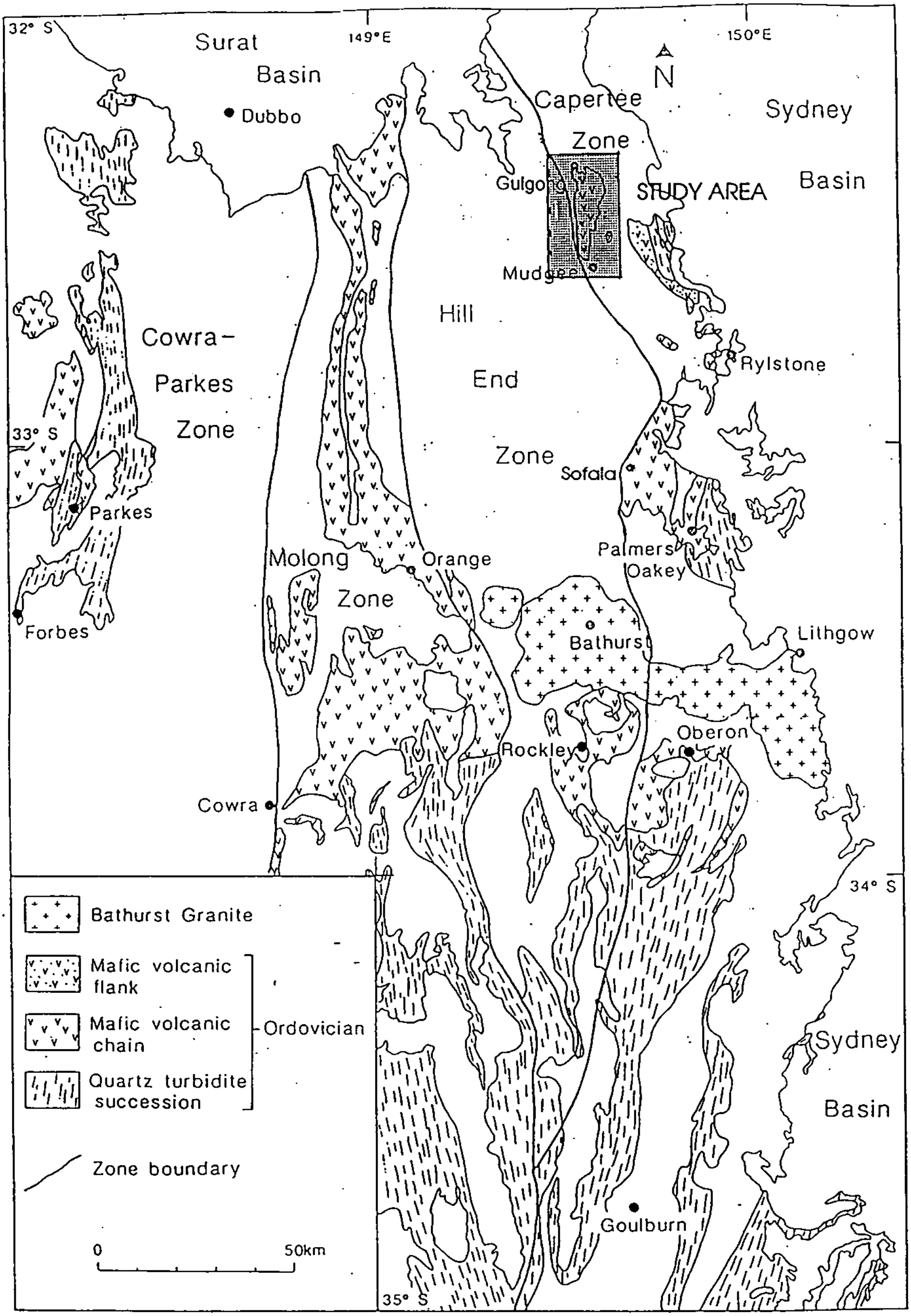


Fig.2. Location of main structural zones (adapted from Scheibner, 1993).

REGIONAL STRATIGRAPHY

Introduction

The first published account of the geology of the district was that by Jones (1940), with a map at 1:31,680 scale of the Gulgong Gold Field. Offenberg et al., (1971) compiled the regional geology of the area as part of the Dubbo 1:250,000 geological sheet and established a stratigraphy for the area which has remained with little modification to the present day. Metallogenic data for the district was compiled by Matson (1973) from published and unpublished material. This data was published on a separate metallogenic map using a modified geological base after Offenberg et al., (1973).

The accompanying 1:50,000 scale geological fact map (Fig. 3, in pocket) was compiled by the author from fieldwork undertaken during the period from July, 1995 to April, 1996. The 1:50,000 scale interpretative geological map (Fig. 4, in pocket) represents a synthesis of geological data and interpreted geophysical data, particluarly magnetic data.

Considerable revision to the Palaeozoic stratigraphy of the area was required. This is shown in Fig. 5 which is a time-space diagram showing the previous and revised nomenclature for the area.

The newly revised stratigraphy of the area encompasses elements of an Ordovician volcanic belt and a Late Silurian shelf sequence located to the west of the Late Silurian to Early Devonian Hill End Trough sequence (Fig. 6). Together, these units form a westward-younging sequence that is similar to that found at Sofala about 70 km to the south.

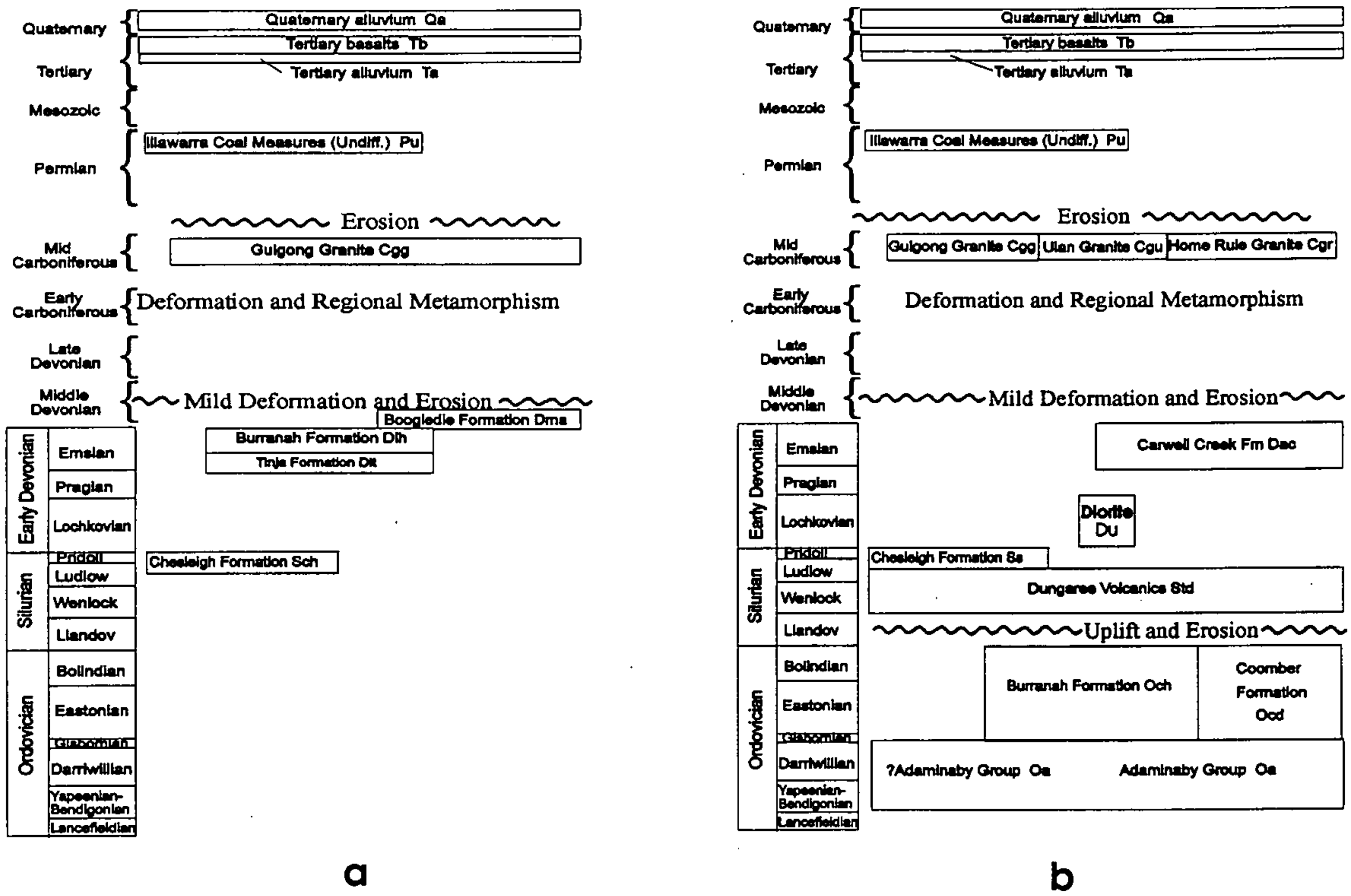
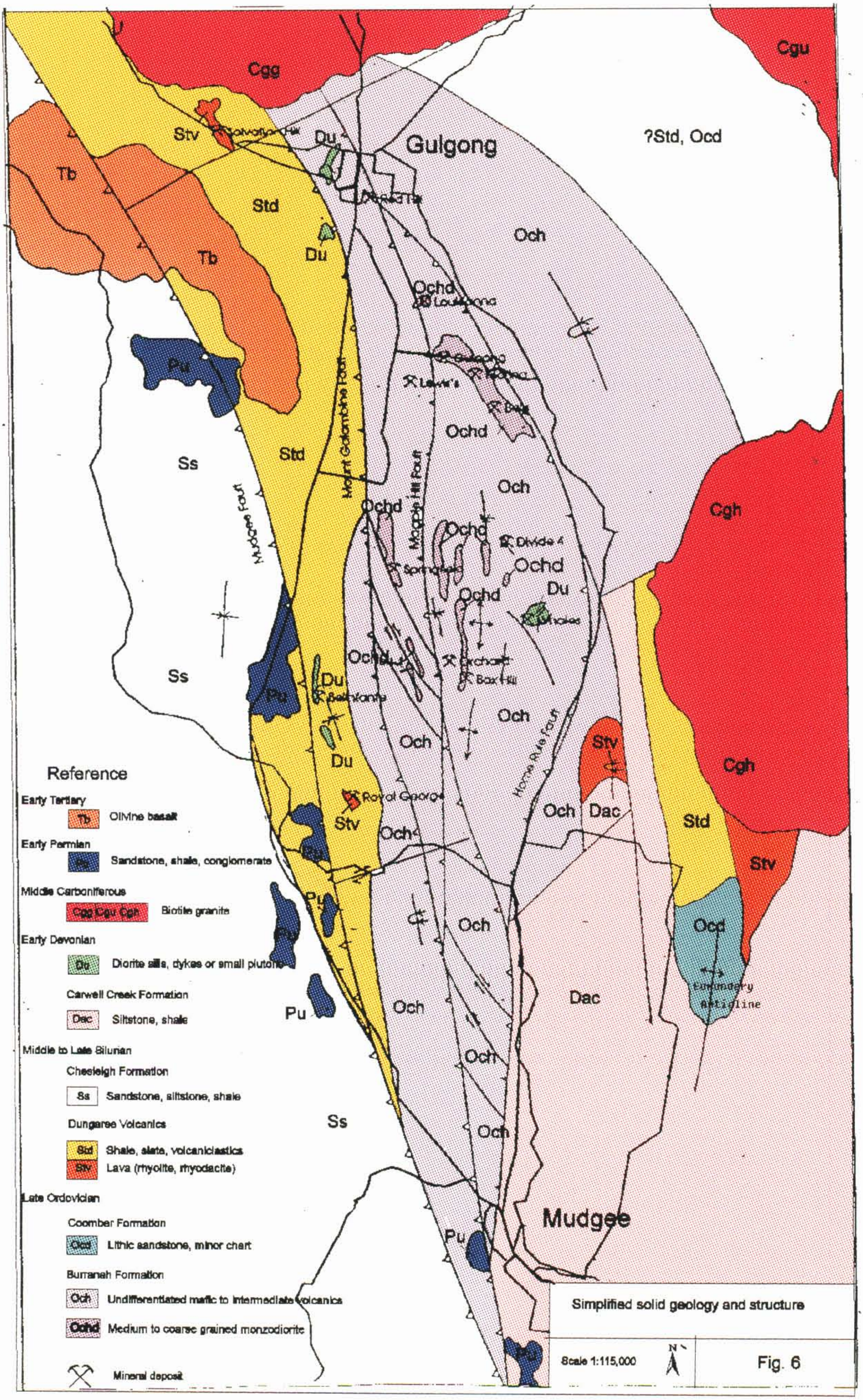


Fig. 5. Time-space diagrams for the area showing (a) previous nomenclature and (b) new nomenclature



Simplified solid geology and structure

Fig. 6

Late Ordovician Units

Burranah Formation

The Burranah Formation comprises a north-trending belt of volcanics about 20 km long and 5 km wide between Mudgee and Gulgong (Fig. 6). The name Burranah Formation was first used for this belt by Offenberg et al. (1971) and assigned an Early Devonian age based on palaeontological work by Exon, (1962). This study continues this usage of the name but assigns a Late Ordovician age based on new fossil evidence. Results of geochemical and isotope studies of the Burranah Formation compare favourably with other known Ordovician units in the Lachlan Fold Belt. The Burranah Formation also has a distinctive red (potassic) radiometric signature that is characteristic of many of the Late Ordovician volcanics (particularly shoshonites) of the Lachlan Fold Belt.

The Late Ordovician Burranah Formation and its distal equivalent, the Coomber Formation, are the oldest stratigraphic units exposed in the area. Evidence from new mapping to the south, on the Bathurst 1:100 000 sheet (Watkins, in prep.) and the Mudgee 1:100 000 sheet (Colquhoun et al., 1996), suggests that both of these units are underlain, or in part interfinger with, the Early Ordovician Adaminaby Group. The Adaminaby Group is a quartz turbidite fan deposit that has now been recognised throughout much of the Lachlan Fold Belt in eastern New South Wales (Ferguson et al., in press).

The Burranah Formation dominantly comprises a syn-eruptive and post-eruptive sequence of intermediate to mafic volcaniclastic sandstone and breccia accompanied by minor coherent lava, intrusions, and non-volcanic sedimentary rocks. The unit is poorly exposed and shows rapid lateral facies changes which together make it difficult to distinguish an internal stratigraphy.

Syn-eruptive volcaniclastic deposits

Resedimented syn-eruptive deposits occur throughout the Burranah Formation. Coarse grained volcanic breccias form units with outcrop widths up to 100m and strike lengths of up to 1 km. Individual units are very thickly bedded and are generally unsorted. They are matrix supported and contain angular lithic blocks up to 20 cm in a sandy martix (Fig. 7). The deposits are essentially monolithologic with clasts of latite composition and often show a crude reverse grading and bedforms that indicate rapid deposition. Resedimented hyaloclastite breccia is also present and forms medium bedded units with little lateral extent. Fig. 8 shows a matrix supported hyaloclastite breccia with a chlorite altered fine grained volcaniclastic sediment matrix. The clasts are aphanitic latite and are also chlorite altered.

Volcanic sandstone and siltstone

Juvenile, clast-rich volcaniclastic sandstones and siltstones form the principal volcanic facies of the Burranah Formation. The sandstones are the dominant facies and generally consist of fine to medium grained, well sorted, angular, volcanic lithic fragments (usually latite) and minor crystal fragments. Beds vary from thinly bedded to very thickly bedded and they can form both massive ungraded units and graded turbidite units interbedded with siltstones. There is little evidence for any traction current reworking.

Intermediate and mafic lavas

Lavas are relatively uncommon and generally form massive units up to 5m thick which can be traced for up to 10 m to 15 m along strike. The lavas are compositionally dominated by potassium-rich latites (extrusive equivalent of monzonite) but also include absarokites and shoshonites. They are generally chlorite altered and porphyritic, carrying feldspar and/or euhedral phenocrysts of clinopyroxene. Rare pillow basalts are also present.

Fig. 7. Coarse grained volcanic breccia unit with matrix supported angular lithic blocks in a sandy matrix.

Fig. 8. Resedimented hyaloclastite breccia. Clasts of chlorite altered quenched latite in a matrix of altered volcaniclastic sediment.

Syn-volcanic intrusions

Medium to coarse grained intrusions of monzodiorite are relatively common within the Burranah Formation. The intrusive bodies range up to 3 km in length by 600 m to 700 m wide and are elongate parallel to the strike of the country rock. They are compositionally similar to the volcanics and are interpreted to be co-magmatic.

The volcanic facies described above are interbedded with a sedimentary facies that comprises massive black (often pyritic) mudstone, graded sandstone turbidites, conglomerates and breccias of mixed provenance. The breccias often contain clasts of limestone and have rare red (oxidised) volcanic clasts. Poor outcrop and rapid facies changes make it difficult to distinguish an internal stratigraphy, however an interpretation of the airborne magnetic data and measured structural data suggests the Burranah Formation can be sub-divided into two main magnetic packages. The lower package (V1, Fig. 4, Fig. 9, Fig. 11) has a moderate to high magnetic signature and a high proportion of coherent volcanics, and breccias. The upper package (V2, Fig. 4, Fig. 9, Fig. 11) is less magnetic and consists dominantly of volcaniclastic sandstone, comagmatic intrusions and sediment. Although these magnetic packages cannot be mapped, they have been incorporated into the interpretative cross-section (Fig. 9) as a guide to the internal structure of the Burranah Formation.

The presence of black pyritic mudstone, abundant mass flow deposits (including turbidites), hyaloclastite and pillow lava provide evidence for a dominantly below storm wavebase, submarine setting. However the presence of numerous limestone blocks also suggests the volcanics were partly emergent with fringing reefs.

The Burranah Formation is now regarded as Late Ordovician. This age is based on the identification by J. Pickett (pers. commun.) of the corals *Plasmoporella* sp., *Nyctopora* sp., and *Heliolites* sp., plus the ubiquitous Ordovician alga *Vermiporella* sp. in limestone clasts from a debris flow unit north of Mudgee. Pickett (1978) reported the same coral and alga, together with a Gisbornian conodont fauna, from limestone clasts in a breccia from the Late Ordovician Sofala Volcanics, 80 km to the south. The total thickness of the Burranah Formation is estimated from the interpretative cross section (see Fig. 4) to be 2.5 km.

The Coomber Formation

The Coomber Formation occurs in the core of the Eurundury Anticline in an area formerly mapped by Offenberg (1971) as part of the Early Devonian Boogledie Formation. In the Eurundury Anticline area, the Coomber Formation is unconformably overlain by the Late Silurian Dungaree Volcanics and the Early Devonian Carwell Creek Formation. The formation was named by Pemberton et al (1994) for a thick succession of lithic sandstone, mudstone, radiolarian chert with minor mafic lavas and conglomerate occurring along the Cudgegong River near Rylstone to the southeast of Mudgee.

In the Mudgee-Gulgong district, the Coomber Formation is dominated by massive lithic sandstones. It has a distinctive red (ie., potassic) radiometric signature that is similar to the Burranah Formation and many other Ordovician volcanic units in the Lachlan Fold Belt. The massive and thick-bedded nature of the lithic sandstones is consistent with deposition by high density turbidity currents in a deep marine environment. The Coomber Formation has not been dated directly, but on stratigraphic grounds it is thought to be a distal equivalent of the Burranah Formation.

Silurian Units

Dungaree Volcanics

The name Dungaree Volcanics was first used by Offenberg et al., (1971) for a belt of felsic volcanics west of Rylstone and Kandos. The unit was assigned to the local name Moonbucca Formation by Pemberton et al., (1994) but the original name has now been re-introduced.

The Dungaree Volcanics comprise a Middle to Late Silurian succession that unconformably overlies or is faulted against the Burranah Formation and Coomber Formation. In the western part of the area, the unit is overlain by the Chesleigh Formation with apparent conformity and its areal extent corresponds approximately to that previously mapped as the Early Devonian Tinja Formation

The Dungaree Volcanics consist of a 700 m thick volcanic sequence that becomes increasingly sediment dominated towards the top. The volcanic-rich base consists of felsic volcaniclastic arenite with thick beds of coherent rhyolite and rhyodacitic lava (rarely flow banded) and rare autochthonous limestone. The top of the unit is dominated by non-volcanic shale.

An age of 416 ± 5 Ma was obtained by U/Pb SHRIMP techniques for zircon from dacite lavas of the Dungaree Volcanics to the south of the study area (Colquhoun et al., 1996). Within the study area, an autochthonous limestone pod was located towards the base of the unit about 1 km southeast of Mount Galambine. The limestone from this site contained the following Mid to Late Silurian (Wenlock-Ludlow) fauna:

Rugose corals: *Phaulactis shearsbyi; Tryplasma* sp.
Tabulate corals: *Favosites* sp.; ?*Favosites lichenaroides*; *Coenites* cf. *juniperinus*; *Coenites* cf. *pinaxoides.*

Stromatoporoids: *Ecclimadictyon* sp.; *Densastroma* sp.; ? *Parallelostroma* sp.
Algae: *Solenopora* sp.; *Ortonella* sp.
Brachiopods: *Kirkidium* sp.

The presence of coral and a shelly fauna toward the base of the unit with flow banded rhyolite suggests that the Dungaree Volcanics were deposited in a shallow marine to emergent shelf environment that the preceded deeper-water sedimentation in the Hill End Trough.

The Dungaree Volcanics in the map area are lithologically similar to a number of other Middle to Late Silurian units that also overlie Ordovician rocks to the south of the study area. These include the Willow Glen Formation and Windamere Volcanics in the Cudgegong district (Pemberton, 1990); the Tanwarra Shale and Bells Creek Volcanics in the Sofala district (Packham, 1969); and the 'mudstone-limestone facies', west of Capertee (Bishoff and Fergusson, 1982). Correlatives of the Dungaree Volcanics also occur on the western side of the Hill End Trough and include the Mullions Range Volcanics. The Mullions Range Volcanics host the important Lewis Ponds polymetallic massive sulphide deposit and the Mount Bulga massive sulphide deposit. These units also have shallow marine settings and were probably contemporaneous with the Dungaree Volcanics.

In the Eurundury Anticline area the Dungaree Volcanics contain weakly disseminated pyritic sulphides and thin quartz veins. This weak dispersed mineralisation may have been a contributing source to the small alluvial gold deposits found in streams that drain this area to the west.

Chesleigh Formation

The Middle to Late Silurian Chesleigh Formation conformably overlies the Dungaree Volcanics in the western part of the study area where it forms the basal unit of the Hill

End Trough. The name was first published by Dulhunty and Packham (1962), and later defined by Packham (1969). The Chesleigh Formation is a deepwater turbiditic unit with several horizons of felsic volcanics towards the top. The turbidites show considerable variation in the sand and shale ratio, with sandstones becoming thinner and less prevalent towards the top. Only the basal part of the Chesleigh Formation crops out within the study area and consists of interbedded quartz-lithic and feldspar-lithic sandstone with minor quartz siltstone and shale.

Early Devonian Units

Carwell Creek Formation

The Carwell Creek Formation occurs to the northeast of Mudgee around the Eurundery Anticline where it unconformably overlies the Dungaree Volcanics and is faulted against the Burranah Formation. In the Eurundury Anticline area, the unit was originally mapped as the Melrose Formation by Wright (1966), and subsequently renamed the Boogledie Formation by Offenberg et al. (1971). To the west of the Eurundery Anticline the unit was previously mapped as the Tinja Formation (Offenberg et al, 1971).

The Carwell Creek Formation is the uppermost unit of the Kandos Group (Pemberton et al, 1994) and crops out extensively in the Rylstone-Cudgegong district about 80 km to the south. In this area, the unit comprises over 1000m of siliclastics and carbonates deposited in barrier island and shoreline settings (Pemberton et al, 1994; Colquhoun, 1996).

In the Mudgee-Gulgong district, the Carwell Creek Formation consists dominantly of poorly outcropping siltstone and shale. A more resistive ridge-forming sandstone unit occurs at the base of the formation and forms a distinctive low ridge that outlines the Eurundery Anticline.

The lower sandstone unit is composed of iron stained, massive, fine to coarse-grained quartz, quartz lithic and quartzofeldspathic sandstone, with minor pebbly sandstone, siltstone and conglomerate. A fossil horizon occurs near the middle of this unit containing spirifers, crinoid ossicles and gastropods. The upper part of the unit consists of a poorly outcropping and monotonous sequence of siltstone and shale with minor pebbly and crinoidal tuffaceous sandstone. A thin limestone horizon occurs high in the unit,

Vertical (skolithos type) burrows, tabular cross beds and channels, common disarticulated crinoids and occasional ?reed fragments suggest a near shore shallow marine depositional setting. An Early Devonian age (Late Pragian to Early Emsian) was suggested for the unit by Colquhoun (1995) for the Rylstone-Cudgegong area based on conodonts, brachiopods and corals. A new fossil site located 10 km north of Mudgee produced a diverse shelley fauna with a probable Late Emsian age (T. Wright, pers commun.). Exon (1962), reported an Early Devonian age for corals, a trilobite, gastropods, molluscs, bryozoans, and fossil wood from the brick pit quarry north of Mudgee (previously mapped as Tinja Formation).

The Carwell Creek Formation represents the uppermost unit of an extensive shallow marine platform sequence located on the Capertee High during the Early Devonian. The presence of the Carwell Creek Formation in the map area now represents the northernmost occurrence of the unit and a similar palaeogeographic setting for this part of the Capertee High during the Early Devonian.

Diorites

Small diorite intrusives were recorded west of Gulgong and at the abandoned Red Hill mine (now located within the Gulgong town boundary) by Jones (1940) and Offenberg (1971). They were thought to be associated with the nearby Gulgong Granite and were assigned a similar Carboniferous age. However a number of additional occurrences have now been located to the south of Gulgong which also host gold mineralization. At the

Belinfante Deposit (deposit no. 13, Fig. 3), a diorite dyke intrudes the Dungaree Volcanics and at the Whales Deposit (deposit no. 10, Fig. 3) a small circular diorite body intrudes the Burranah Formation.

The diorites are composed of interlocking, euhedral, fine to coarse-grained plagioclase crystals (typically albite) with minor pyroxene. The feldspar is often weakly altered to carbonate and sericite and microveins of carbonate are also present.

An age of 409 ± 7 Ma was obtained by U/Pb SHRIMP techniques for zircon from the diorite body at the Whales Deposit. The diorites near Gulgong, and the new additional occurrences, have similar whole rock geochemistry that is also distinct from the Carboniferous granites. They are all now regarded as part of the same Early Devonian magmatic event.

Middle Carboniferous

Large areas of granite occur to the north, northeast and southeast of Gulgong (Fig. 6) that were previously regarded as a single batholith referred to as the Gulgong Granite (Offenberg et al, 1971). New airborne magnetic data however, show the large area can subdivided into three plutons. These have been named the Gulgong Granite, the Ulan Granite and the Home Rule Granite.

The granite bodies have all been passively emplaced and intrusive relationships between the three plutons suggest that they young to the south. All three granites are discordant, unfoliated, post-deformation I-type, biotite granites intruded at high crustal levels. The Gulgong Granite is faulted on its southern and western sides and the Home Rule Granite is cut by numerous northeast and northwest-trending fractures and late stage dykes. A 318 Ma (Middle Carboniferous) age has been determined from K/Ar ratios of biotite separates for the Ulan Granite (Jones, 1986).

Early Permian

Early Permian rocks (part of the Illawarra Coal Measures) are restricted to the western part of the map area and occur as thin, flat-lying veneers that overlie older rocks with angular unconformity. The sediments consist predominantly of fine and coarse-grained sandstone, conglomerate and shale, with occasional lenticular beds of carbonaceous shale that pass into thin coal seams. Glossopteris is abundantly distributed throughout. The basal unit consists of coarse conglomerate ranging from 6 m to 15 m in thickness. Gold has been mined from these basal conglomerates at Slashers Flat, about 7.5km northwest of Mudgee.

Early Tertiary and Quaternary

The early history of Gulgong is associated with the mining of gold from the Early Tertiary alluvial deposits (deep leads). The Early Tertiary deep leads follow down palaeo-valleys which have their headwaters in the Burranah Formation. The more accessible shallow parts of the deep leads were only 1.5 cm to 4 cm in thickness and were quickly mined out. The sediments within the leads were mostly gravel, sand and mudstone (Jones, 1940).

Early Tertiary olivine basalt crops out extensively to the west of Gulgong where it follows a northwest-trending palaeo-valley. Basalt also occurs in many of the deep leads (Rayner, 1940), where flows up to 50 m thick cap the Early Tertiary alluvial deposits. Dulhunty (1972), reported K/Ar dates of 15.2 Ma and 14.2 Ma (Middle Miocene) for the basalts to the west of Gulgong.

Extensive deposits of Quaternary alluvium, colluvium, and residuum occur throughout the area and mask much of the bedrock geology. Alluvial deposits of unconsolidated sand, gravel and clay are associated with the Cudgegong River and its tributaries. The modern drainage system has also been worked in many areas for small amounts of alluvial gold.

REGIONAL STRUCTURE

The Mudgee-Gulgong district lies mostly within the Capertee Structural Zone of Scheibner (1993). To the west are elements of the Hill End Structural Zone and outliers from the Sydney Basin Zone are preserved west of Gulgong

The Sydney Basin strata are for the most part, flat lying and undeformed. Strata of the Hill End Zone, in the west of the map area, are characterised by open, south-plunging, north to north northwest-trending folds and few faults. The Capertee Zone however contains north northwest-trending folds, several major thrusts, north trending oblique-slip faults and numerous northwest and northeast-trending faults. The Capertee Zone and the Hill End Zone are separated by the northern continuation of the Mudgee Thrust (Fig. 4).

Evidence for significant pre-cleavage deformation is meagre and refold patterns observed in Ordovician strata to the south (eg, Capertee area, Ferguson, 1979; Glen and Watkins, in prep.) are not found in the Mudgee-Gulgong district. A weak pre-Late Silurian D_1 has been reported for the Orange area of the Lachlan Fold Belt by Glen and Watkins (1994)

In the Eurundury Anticline there is an angular unconformity between Late Ordovician Coomber Formation and the Late Silurian Dungaree Volcanics. However a lack of structural data close to the contact makes it difficult to gauge the degree of angular discordance. Unconformities exist on both sides of the Hill End Trough at the base of the Late Silurian, and indicate that the trough opened during the Early Silurian (Glen and Watkins, 1994).

Although it is probable that the Late Ordovician rocks were deformed before deposition of the overlying Late Silurian units, it is not possible to identify any structures in these rocks that are not present in younger rocks.

An angular unconformity is also present between the Late Silurian Dungaree Volcanics and the Early Devonian Carwell Creek Formation. However the degree of angular discordance is low and this break may best be attributed to erosion due to sea-level fall or very gentle uplift and tilting. Unconformities are also widely developed to the south of the study area where Powell and Edgecombe (1978) found a low angle discordance between Early and Late Devonian sequences in a structural study of the Mount Frome syncline. They concluded that erosion, uplift and broad tilting had occurred during the Middle Devonian Tabberabberan Orogeny.

The major Early Carboniferous deformation (D_2) (Powell and Edgecombe, 1978) was responsible for the majority of folding, thrusting and cleavage formation in the study area. The Hill End Zone is characterised by generally tight, upright F_2 folds with long planar limbs and angular to rounded hinges, normally with axial plane cleavage well developed. F_2 folds typically plunge at shallow angles to the south. D_2 structures in the Capertee Zone are considerably more varied and complex. The major separating structure, the Mudgee Thrust, is a steeply west-dipping thrust fault with Hill End Zone sediments thrust eastwards over Capertee Zone rocks.

East of the Mudgee Thrust D2 was responsible for at least two generations of faults. Early faults are commonly steeply west-dipping faults parallel to strike such as the Mount Galambine Fault, the Magpie Hill Fault and the Home Rule Fault (Fig. 6). Shear sense indicators preserved on the Mount Galambine Fault indicate the hanging wall has moved to the east. A later series of faults is also present and cuts across the prevailing strike and fold axis at high angles. North to northwest-trending F_2 folds are generally tight with shallow plunges to the south. Doubly plunging folds are present in the Burranah Formation between the Magpie Hill Fault and the Home Rule Fault. Cleavage (S_2) within the Burranah Formation is poorly developed but generally axial planar to the major folds. Within the Burranah Formation footwall synclines are developed east of the Magpie Hill

Fault and east of the Home Rule Fault. The Magpie Hill Fault has shear sense indicators that suggest dextral oblique-slip movement and together with the Mount Galambine Fault define a 1 km wide zone that has undergone dextral, oblique-slip deformation. Several folds in the footwall of the Magpie Hill Fault have their western limbs truncated by this fault indicating a period of later movement that postdated the folding event. Considerable shortening has taken place between the Mudgee Fault and the Home Rule Fault within the Burranah Formation and Dungaree Volcanics (Fig. 9). Between these two faults is a zone of higher strain in which most of the known primary gold deposits are located.

During the Carboniferous, the northeastern Lachlan Fold Belt was located in a backarc setting to the west of the well developed east-facing margin of the New England Fold Belt (Murray et al., 1987). Regional deformation (D_2) of the northeastern Lachlan Fold Belt, in the Early Carboniferous, coincides with development of a subduction complex in the eastern New England Fold Belt (eg. Fergusson et al., 1993).

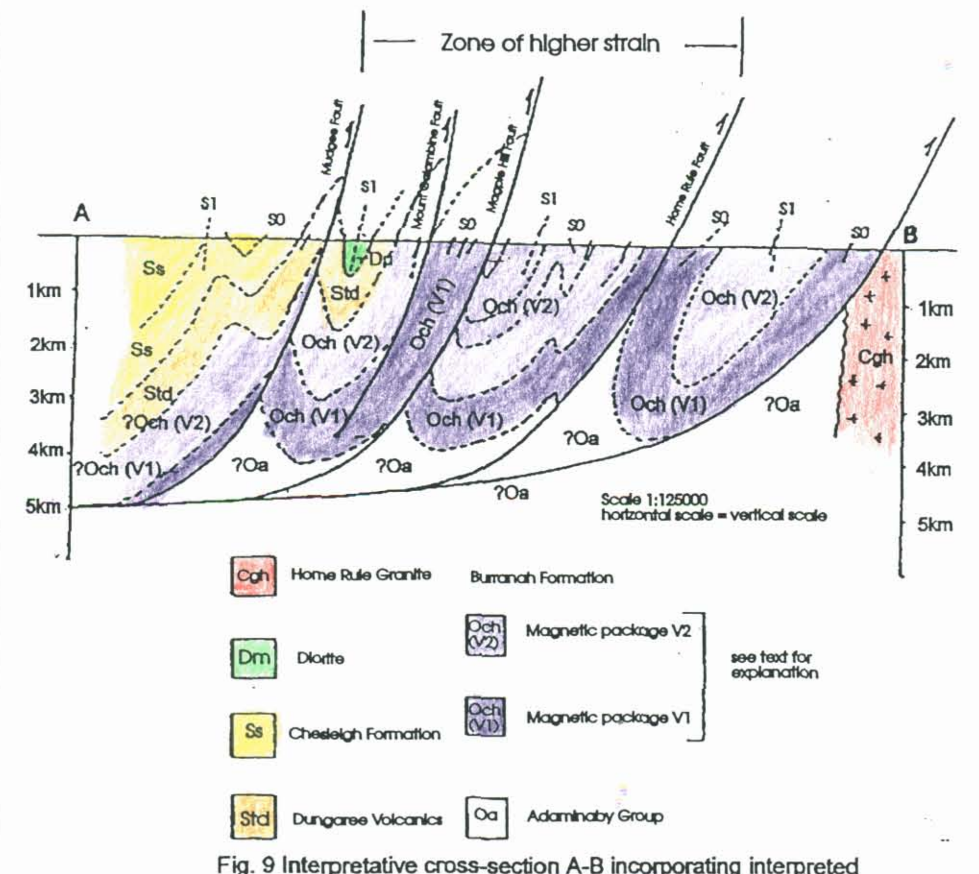


Fig. 9 Interpretative cross-section A-B incorporating interpreted magnetic units (V1, V2) of Burranah Formation

GEOPHYSICS

DATA COVERAGE

The Mudgee-Gulgong district lies within the Dubbo 1:250,000 sheet area. This area is now covered by high resolution gravity, magnetic and radiometric data. The aeromagnetic and radiometric surveys were flown in 1991 by the Australian Geological Survey Organisation (AGSO) using flight line spacings of 400m. However to improve resolution the Department of Mineral Resources provided additional funding for 250m interline spacing over parts of the Molong and Capertee Zones including the central part of the Mudgee-Gulgong area. The average mean terrain clearance was 100 m. The gravity data acquired by AGSO in 1973 using an approximate square grid of 11 km and was infilled by the Department of Mineral Resources to an approximate grid spacing of 4.0 km.

Several transforms were applied to the grided magnetic data including Reduction to the Pole (RTP) and RTP first vertical derivative. Image processing was applied to the grided data to produce final pseudocolour and greyscale products of Total Magnetic Intensity (TMI) magnetics, RTP-TMI magnetics and their first and second vertical derivatives. The grided K-U-Th radiometric data was contrast enhanced and combined to produce RGB colour composite images. Interpretation of the magnetic and radiometric data was undertaken with images produced at a scale of 1:50,000. The residual gravity data was illuminated with an artificial sun from the east to enhance the north-south structural grain.

GRAVITY

Fig. 10 is and image of the residual gravity data for the Mudgee-Gulgong region. The image shows a major continuous gravity ridge extending from south of Ilford to Gulgong. Outcropping Ordovician volcanic rocks such as the Burranah Formation and the Cudgegong Volcanics, are associated with gravity highs along this ridge while elsewhere along the gravity ridge the response is more subdued. To the west and northwest of Gulgong the gravity ridge becomes a broad area with a high gravity response. This area is located beneath the fill of the Hill End Trough and suggests that Ordovician volcanics may form a considerable part of the basement of this area.

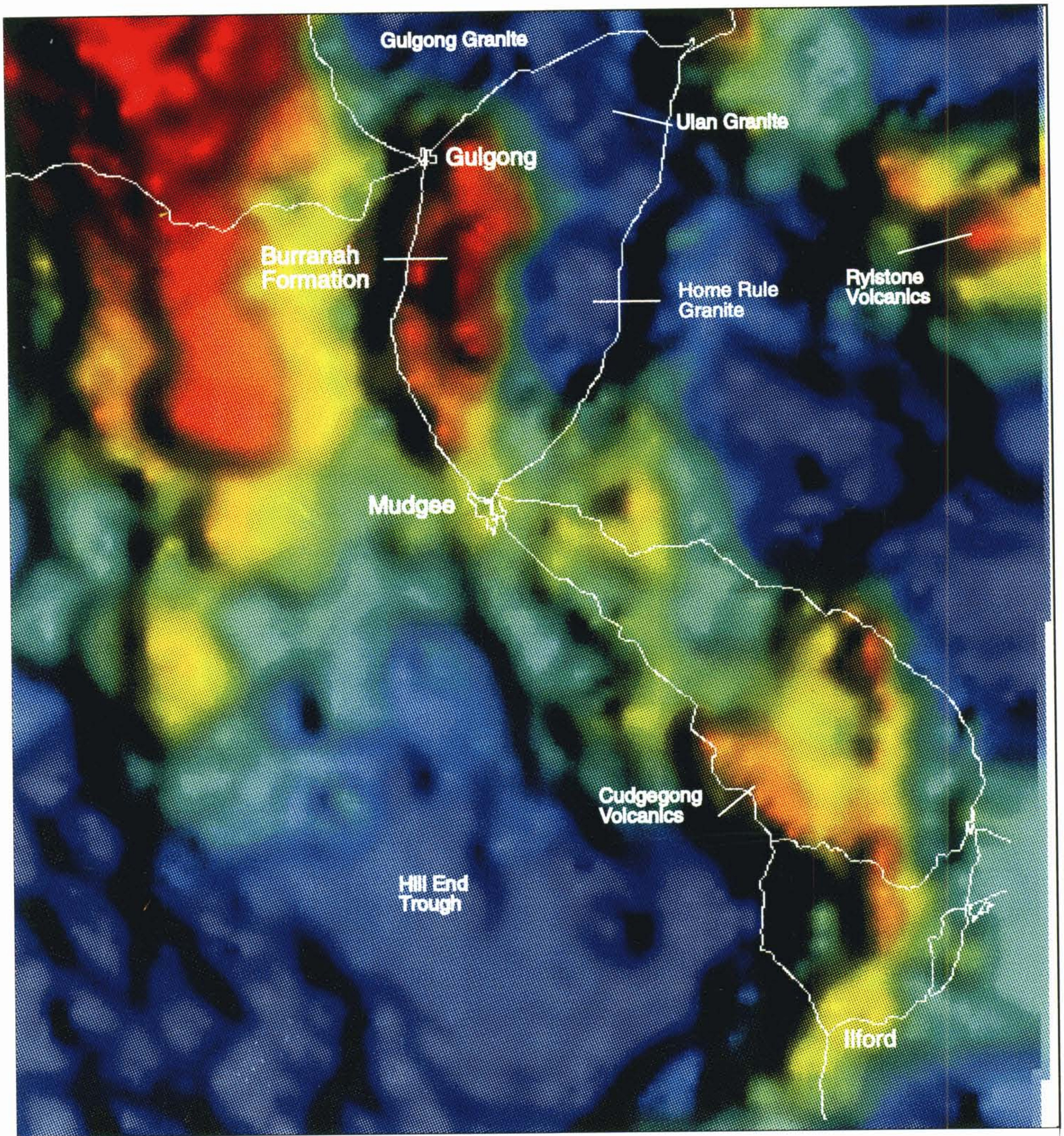
The three Carboniferous granites, The Gulgong Granite, the Ulan Granite and the Home Rule Granite are all represented by well-defined gravity lows. The northwest trending domains of gravity highs to the northeast of the Burranah Formation are located under Permian cover of the Sydney Basin but are thought to be expressions of the Early Permian Rylstone Volcanics.

MAGNETICS

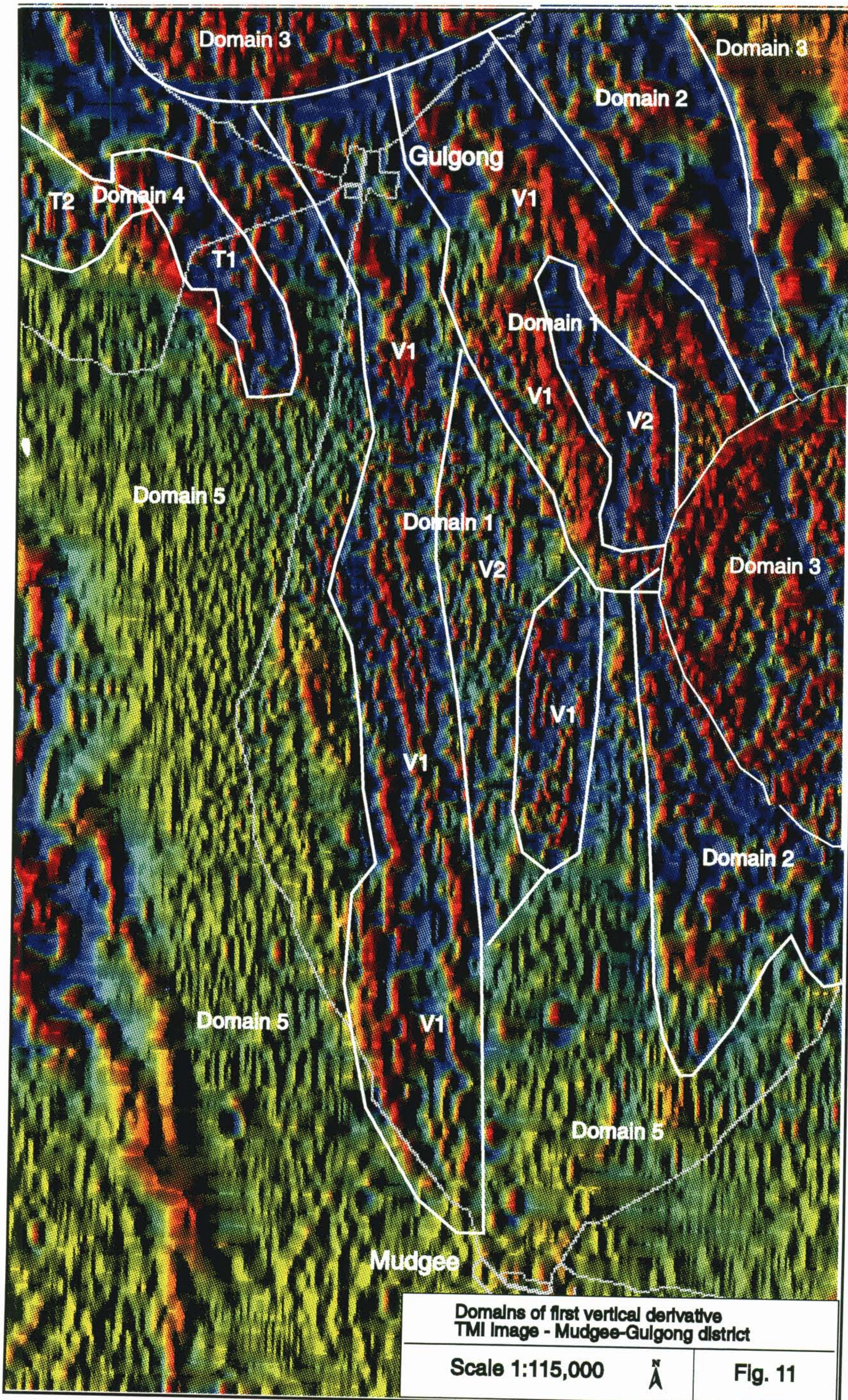
Geological mapping and interpretation of the Mudgee-Gulgong district was greatly aided by the magnetic data, particularly the first derivative pseudocolour TMI image. This data shows major and subtle magnetic units and linears, allowing interpretation at a regional as well as a local scale. Outcrop magnetic susceptibilities were collected during mapping to aid interpretation (Table 1).

TABLE 1. Ranges of Outcrop Magnetic Susceptibilities

Unit	Rock Type	Range (SI units x 10^{-5})
Burranah Formation	Monzodiorite	30-1500
	Lavas	1000-4000
	Volcanic breccia	40-2500
	Volcaniclastic sandstone, siltstone	10-100
Early Devonian Diorite	Fresh diorite	50-1000
	Altered diorite	10-100
Carwell Creek Formation	Siltstone	10-25
Gulgong Granite	Granite	10-50



Scale 1:400,000	Image of residual gravity for the Mudgee-Gulgong district	Fig. 10



Domains of first vertical derivative
TMI Image - Mudgee-Gulgong district

Scale 1:115,000	Fig. 11

Fig. 11 is a first vertical derivative TMI pseudocolour image of the Mudgee-Gulgong district. The image has been divided into five main domains based on the intensity and character of the magnetic response.

Domain 1

Domain 1 incorporates the Burranah Formation. It is characterised by generally linear, moderate to high intensity anomalies within a background area of generally low intensity response. Within this domain there are two principal subdomains termed V1 and V2. Subdomain V1 has a variable moderate to high response and subdomain V2 has a variable but generally low to moderate response. Domain V1 consists dominantly of primary volcanic rocks and breccias while domain V2 is composed dominantly of volcaniclastic rocks, small intrusions and sediments.

Subdomain V1 forms a north-south-trending belt on the western side of the Burranah Formation and outlines a previously unrecognised extension of The Burranah Formation to the east of Gulgong. The western subdomain is fault bounded and has several narrow magnetic units that have north-nortwesterly trends. Offsets on many of these units have been interpreted as faults that have dextral senses of movement. The subdomain area east of Gulgong is interpreted to form a south-plunging syncline under a thin cover of Quaternary alluvium. Subdomain V1 effectively surrounds most of V2. Subdomain V2 has numerous north-south trending narrow magnetic units which often form fold closures.

Several faults are interpreted from within this domain. The Mount Galambine, Magpie Hill and Home Rule Faults are represented as narrow linear corridors of low magnetic intensity that also form boundaries, in part, to the V1 and V2 subdomains. Several late, northeast trending faults cut across both the V1 and V2 subdomains and have both dextral and sinistral senses of movement.

Domain 2

Domain 2 is characterised by groups of small, circular, coalescing high intensity anomalies. The southern area corresponds to the Eurundery Anticline that contains rocks of the Coomber Formation and Dungaree Volcanics. The northern area is entirely under Cainozoic cover and may represent additional occurrences of these units.

Domain 3

Domain 3 comprises three distinctive broadly circular high intensity magnetic areas that are interpreted as three separate granitoids referred to earlier as the Gulgong Granite, the Ulan Granite and the Home Rule Granite. The Gulgong Granite and the Home Rule Granite have a similar high magnetic response but the Ulan Granite is less well defined. The Ulan Granite and the Home Rule Granite are transected by several narrow late stage dykes. A strong linear magnetic low trends southwesterly across the southern edge of the Gulgong Granite.

Domain 4

Domain 4 is located to the west of Gulgong and comprises an area of generally low magnetic response. The domain defines the main area of Tertiary basaltic lava flows and can be divided into two subdomains that represent separate flows. Subdomain T1 is a northwest trending area about 7 km long by 1 km wide with a generally smooth low magnetic intensity core surrounded by a high magnetic intensity rim. This subdomain crosscuts the smaller subdomain T2 immediately to its west that has a slightly higher overall magnetic intensity. Subdomain T2 represents a slightly older basaltic lava flow.

Domain 5

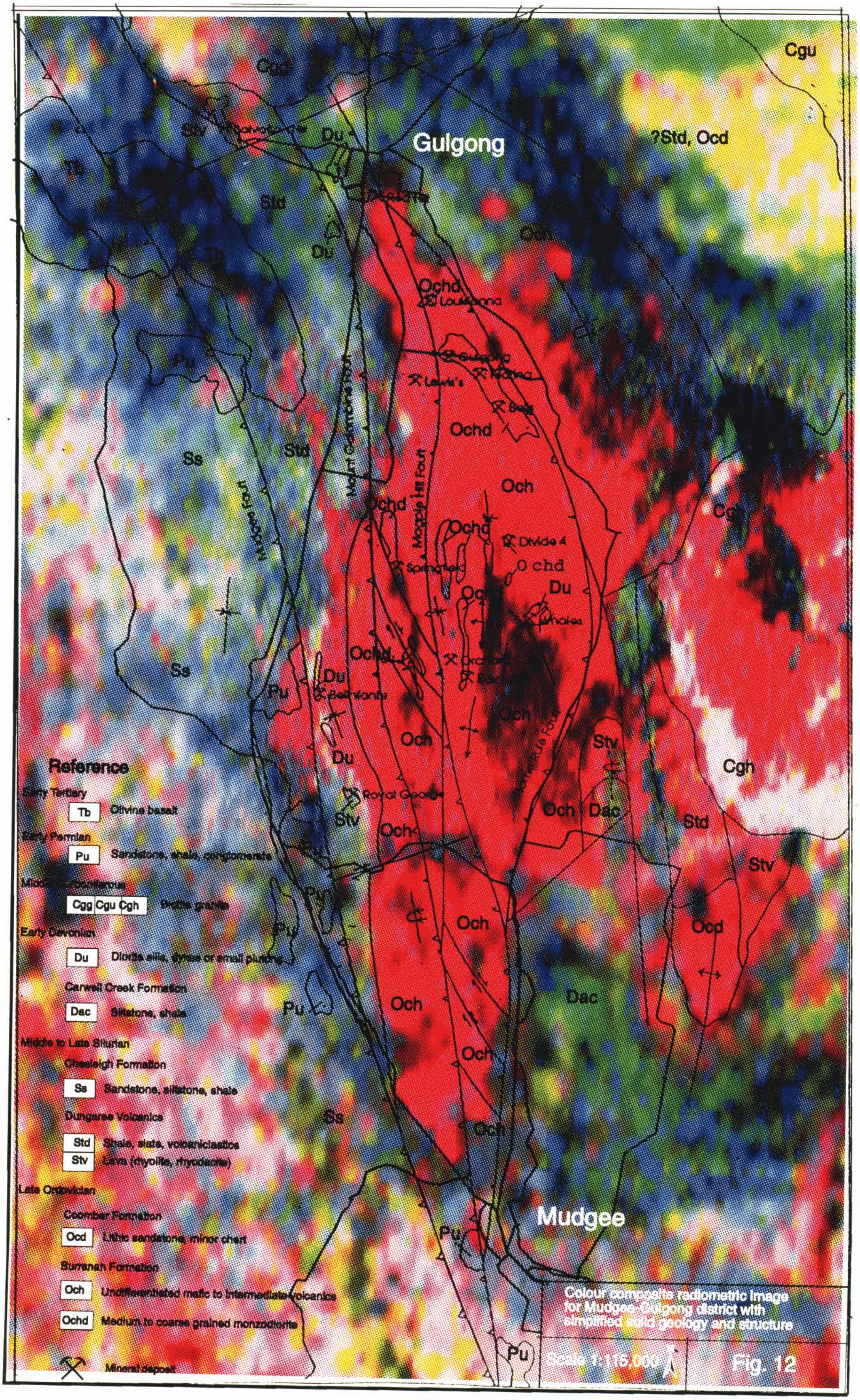
Domain 5 comprises the remainder of the study area and is characterised by generally low magnetic intensity responses. The domain includes units of the Chesleigh Formation, Carwell Creek Formation and the Dungaree Volcanics. In the west of the domain area there are several narrow, linear, high magnetic intensity anomalies that outline a number of broad, open folds. These folds are located within the upper volcanic unit of the Chesleigh Formation in the Hill End Trough and help to define the structural character of this part of the district.

The northern extension of the Mudgee Fault can also be traced through this domain. It is represented as a very narrow linear zone of subtle low magnetic intensity areas that trend north nortwesterly through the district towards the base of the Chesleigh Formation.

RADIOMETRICS

In contrast to magnetic data, radiometric data is a response from probably no more than the top 40 cm to 50 cm of the surficial material. In areas of outcrop, the radiometric response is a reflection of the radiogenic qualities of the outcrop, but this response can become progressively more modified as surficial processes become dominant. In areas of residuum or even colluvium, the response may still reflect the nature of bedrock, however in areas of deep weathering, deep alluvium, or areas modified by agricultural activities, the original radiometric response can be greatly modified. Despite the obvious need for caution in its interpretation, the radiometric data has been a valuable guide in discriminating the main geological units in the study area.

The radiometric image shown in Fig. 12 is an rgb (red, green, blue) colour composite image of the potassium (K), thorium (Th) and uranium (U) datasets with the simplified



Colour composite radiometric image for Mudgee-Gulgong district with simplified solid geology and structure geology. The image has been contrast enhanced using histogram equalisation to maximise the discrimination between geological units.

The Burranah and Coomber Formations

The Burranah Formation constitutes the region of highest relief within the study area. It is dissected by numerous, essentially radially arranged streams that drain mostly away from the area to leave residual soils and minor areas of outcrop. This setting is reflected in the radiometric response that is a strong and mostly uniform red that reflects the potassic (shoshonitic) nature of the volcanic rocks of this formation. Where areas of internal drainage are developed, the radiometric response becomes much darker and almost black eg, in the area to the west of the Home Rule Granite.

Because of the uniform response from the Burranah Formation there is little structural information that can be interpreted from the data. Areas of internal drainage are developed to the west of the Mount Galambine Fault and east of the Magpie Hill Fault.

The Coomber Formation crops out in the core of the Eurundury Anticline along with the Dungaree Volcanics. Outcrop is poor throughout the area and residual soils are well developed. The Coomber Formation has a similar red (high K) response to that of the Burranah Formation and this is probably a reflection of the feldspathic nature of the sandstones which dominate much of this unit.

Dungaree Volcanics

In areas of reasonable outcrop the Dungaree Volcanics have a mixed pinkish-red (high K, low Th, Low U) and white (low K, Low Th, Low U) radiometric response. The response contrasts with the more uniform and darker red response from the Burranah Formation and Coomber Formation and the characteristic yellow and green response from the Lower Chesleigh Formation. To the southwest of Gulgong this response is almost completely modified by the green (Th) response from Quaternary alluvium.

Chesleigh Formation

In the area to the west of Mudgee, the basal section of the Chesleigh Formation displays the yellow and green (low K, high Th, low U) radiometric response typical of many sedimentary units. To the west the Chesleigh Formation develops a more red (high K) response as volcanics become dominant over sediment.

Carwell Creek Formation

The Carwell Creek Formation is a poorly outcropping unit in an area of low relief. The unit has a mottled green and blue response (high Th, high U, low K) north of Mudgee but the response changes to a mottled pink, blue and white in the Mudgee area where soils developed on the unit are extensively cultivated and improved. The response from the northern area is more typical of a sediment response and probably more representative of this unit.

Carboniferous Granites

The Home Rule Granite comprises an area of both red and white radiometric response. The red response is typical of many of the I-type granites in the Lachlan Fold Belt and is developed over areas of low relief with little or no outcrop. The white area (low K, low Th, low U) is developed over the area of highest relief and may represent an early phase of the granite or alteration.

The radiometric response from the Gulgong Granite is largely masked by the blue and black response from younger units while the response from the Ulan Granite is strongly yellow and green, indicative of a relatively high thorium, low potassium, and low uranium composition. An area of colluvium and alluvium developed to the southwest of the Ulan Granite has a similar radiometric response to the Ulan Granite from which it was probably sourced.

Permian Sediments and Tertiary Basalt

Permian sediments and Tertiary basalts crop out to the west and southwest of Gulgong. The radiometric response in this area consists of a mottled blue and white response (high U) from the Permian sediments that becomes a mottled blue and black response (high K, high Th, high U) from areas of Tertiary basalt. The mottled blue and black response is also present to the north and northeast of Gulgong and suggests the presence of additional Tertiary basalt in this area under a very thin cover of Quaternary alluvium.

GEOCHEMISTRY

INTRODUCTION

The Burranah Formation is an intermediate to mafic volcanic unit that now comprises the northernmost occurrence of Late Ordovician volcanics within the Sofala-Rockley Volcanic Belt. The unit has a distinctive red (potassic) radiometric signature and is dominated by rocks of latite composition. These characteristics are unique for volcanic units in the Sofala-Rockley Belt but are similar to areas of known Late Ordovician shoshonitic volcanism elsewhere in the Lachlan Fold Belt such as Goonumbla near Parkes.

The Burranah Formation is the probable primary source of much of the deep lead gold discovered in the Gulgong district last century and is prospective for the discovery further primary deposits of gold and possibly copper. The unit is also however, the most poorly understood. This chapter therefore focuses on the Burranah Formation and distinguishes its geochemical affinities and possible tectonic setting

PETROLOGY

The volcanic rocks of the Burranah Formation are dominated by potassium-rich latites. The unit is intruded by numerous elongated sub-concordant monzodioritic intrusives which are co-magmatic with the volcanics..

The latites consist of phenocrysts of pyroxene and plagioclase in a groundmass of alkali feldspar with interstitial chlorite, magnetite and fine apatite. Plagioclase phenocrysts are mostly albitised. In some latites, plagioclase phenocrysts are locally mantled by alkali feldspar. The monzodiorites have clinopyroxene, plagioclase and alkali feldspar, with biotite and scattered accessory magnetite and apatite. Away from mineralization-related alteration, the Burranah Formation shows lower greenschist facies metamorphic assemblages.

SAMPLING AND ANALYTICAL TECHNIQUES

The limited and variable outcrop of the Burranah Formation precluded any systematic sampling within the unit. The analytical data presented in this study relates to a suite of 21 samples of the least altered, coherent volcanic and intrusive units collected from the available outcrop. Samples were trimmed to remove any weathering surfaces, crushed in a jaw crusher and powdered in an agate ring mill. Analyses were undertaken by Analabs in Perth using the following techniques:

XRF - major elements and As, Ba, Ga, Nb, Rb, Sb, Sn, Sr, Y, Zr.
ICPMS - Ag, Bi, Ce, Co, Cs, Cu, Dy, Er, Eu, Gd, Hf, Ho, La, Li, Lu, Mo, Nd, Ni, Pb, Pr, Sm, Ta, Tb, Th, Ti, Tm, U, W, Yb, Zn, Au, Pt, Pd.
ICPOES - Sc, Cr, V, Ti.
Wet Chemistry - FeO.
Gravimetry - H_2O^-.

Major and trace element analyses for the Burranah Formation (Table 2), are shown with sample numbers and grid references which relate to the Dubbo 1:250,000 sheet. The major element analyses have been recalculated to 100 percent anhydrous to remove variations due to different loss on ignition values.

TABLE 2. Whole-Rock Analyses, Recalculated Volatile-Free, from the Burranah Formation

Sample	G95/453	G95/222	G95/461	G95/340	G95/454	G95/452	G95/456	G95/459	G95/347	G95/011	G95/450
Easting	742300	739160	740673	739280	742180	740998	738860	738900	772933	742000	739775
Northing	6401440	6399980	6406014	6396800	6401460	6412075	6407600	6405517	6374071	6401040	6405373
SiO2	46.17	48.53	49.66	49.08	52.37	51.99	54.04	54.24	51.76	54.59	54.85
TiO2	1.03	0.57	0.49	0.48	0.87	0.95	0.9	0.55	0.86	0.74	0.68
Al2O3	14.6	10.77	11.13	10.7	14.42	17.99	19.42	15.88	13.48	17.21	16.81
Fe2O3total	15.8	11.2	10.4	12.3	10.96	9.04	6.61	8.84	11.22	6.78	7.34
MnO	0.25	0.18	0.18	0.17	0.17	0.14	0.12	0.14	0.19	0.12	0.13
MgO	9.01	10.4	8.77	13.2	6.95	5.11	2.95	3.91	8.66	3.94	6.26
CaO	8.66	13.61	14.57	10.41	8.68	5.75	4.83	7.67	7.18	5.55	3.91
Na2O	1.39	2.98	2.94	1.67	2.7	4.41	2.65	3.95	2.62	3.65	2.7
K2O	2.77	1.47	1.55	1.72	2.63	3.77	7.93	4.28	3.42	6.86	6.76
P2O5	0.31	0.29	0.31	0.27	0.27	0.85	0.53	0.54	0.6	0.56	0.55
Total	100	100	100	100	100	100	100	100	100	100	100
LOI	9.77	5.72	6.17	4.23	9.03	7.67	8.34	6.6	1.89	4.84	3.84
Cr	294	467	462	484	246	72	59	96	414	59	208
Ni	135	278	181	182	109	52	45	36	198	44	137
Co	62	61	59	67	46	25	20	33	43	18	24
Sc	43	30	34	42	30	15	11	19	25	12	15
V	322	213	230	241	233	342	226	198	312	244	228
Cu	100	115	137	242	70	159	367	224	201	252	179
Pb	10	9	6	13	8	12	13	13	15	30	19
Zn	144	75	82	90	87	82	81	95	109	76	81
As	2.25	2.13	4.28	10.49	5.55	5.48	590.38	9.72	10.29	51.74	4.2
Sb	<.37	6.4	<3.21	<3.15	4.44	8.77	185.33	4.32	<3.09	6.02	<3.15
Pd	6.7	7.5	12.7	15.2	4.9	5.5	3	7.9	7.8	4.3	3.4
Ag	0.2	<0.1	0.1	0.2	<0.1	0.1	0.3	0.1	0.1	-	0.2
Pt	6.9	6.7	6.7	10.5	5.4	1.8	0.9	2.3	4.3	1.8	2.5
Au	2.2	1.1	1.1	4.2	3.3	2.2	132.1	1.1	3.1	15.8	7.4
Hg	0	0	0	0	0	0	0	0	0	-	0
Rb	40	23	17	23	50	82	122	92	22	145	152
Cs	2.04	1.92	0.27	0.44	2.45	2.02	0.82	3.53	8.06	5.71	3.61
Ba	726	819	391	542	872	1369	1912	590	547	1626	1779
Sr	466	562	374	181	402	1435	1322	1278	172	538	1419
Ga	16	13	15	13	13	21	21	18	11	19	23
Li	32.58	22.51	10.6	29.89	28.29	21.5	13.65	7.67	34.17	26.18	14.4
Ta	0.22	0.32	0.11	0.21	0.33	0.22	0.33	0.22	0.21	3.38	0.32
Nb	<3	<3	3.2	<3	<3	<3	4.4	<3	<3	10.6	3.2
Hf	0.79	1.17	0.75	1.15	1.11	1.32	1.66	1.51	1.85	2.32	2.1
Zr	52	42	26	30	54	60	71	65	26	81	67
Ti	5909	3616	2911	3125	4616	4398	4550	3392	5526	4540	4277
Y	19	13	13	15	18	22	17	13	12	16	20
Th	1.08	1.18	0.97	1.1	1.69	1.96	2.3	2.71	1.93	2.53	2.81
U	0.4	0.58	0.43	0.6	0.6	0.8	1.2	1.27	0.81	1.36	1.4
La	10.87	9.78	7.27	6.69	13.2	16.34	16.31	16.53	12.45	15.41	15.76
Ce	20.56	18.56	13.91	13.11	25.52	32.79	33.29	31.55	25.11	29.46	30.05
Pr	2.9	2.14	1.9	1.58	3.28	4.46	4.31	3.94	3.04	3.83	3.87
Nd	12.25	10.35	8.03	7.97	13.2	18.32	16.76	15.13	14.41	14.36	14.92
Sm	3.48	2.67	2.35	2.2	3.44	4.61	4	3.67	3.7	3.17	3.57
Eu	1.21	0.86	0.68	0.77	1.09	1.38	0.99	1.1	1.19	1.13	1
Gd	3.37	2.45	2.14	2.2	2.88	3.73	2.89	2.81	3.5	3.17	3.05
Tb	0.57	0.37	0.32	0.33	0.41	0.57	0.39	0.39	0.51	0.46	0.44
Dy	3.48	2.45	2.03	2.1	2.33	3.4	2.66	2.48	3.29	2.75	2.73
Ho	0.76	0.52	0.44	0.46	0.49	0.72	0.57	0.52	0.73	0.57	0.59
Er	2.13	1.49	1.18	1.26	1.33	1.97	1.55	1.4	2.06	1.69	1.68
Tm	0.3	0.21	0.17	0.19	0.2	0.29	0.24	0.21	0.3	0.25	0.24
Yb	1.91	1.39	1.07	1.15	1.22	1.75	1.66	1.4	1.96	1.58	1.58
Lu	0.22	0.21	0.11	0.21	0.22	0.22	0.22	0.22	0.31	0.32	0.21

TABLE 2. (CONT)

Sample	G95/457	G95/458	G95/449	G95/223	G95/345	G95/460	G95/448	G95/451	G95/455	G95/462
Easting	739134	739517	740000	740720	770652	738793	740424	737991	738330	738860
Northing	6408200	6406518	6405635	6399900	6380565	6484941	6406921	6406404	6404250	6407600
SiO_2	55.06	56.06	55.97	55.85	56.3	56.05	56.7	59.04	59.49	62.96
TiO_2	0.73	0.74	0.71	0.67	0.67	0.61	0.66	0.54	0.63	0.31
Al_2O_3	19.04	18.79	17.65	19.51	19.56	18.85	19.42	16.54	16.82	19.48
Fe_2O_3total	6.48	6.7	6.95	6.8	6.12	8.12	5.92	7.15	6.67	3.44
MnO	0.11	0.1	0.12	0.13	0.1	0.14	0.08	0.13	0.18	0.08
MgO	3.81	2.7	5.37	3.55	3.14	3.27	2.9	4.78	3.55	0.27
CaO	2.77	3.73	2.21	2.44	3.86	4.05	3.38	3.01	3.72	0.24
Na_2O	4.48	4.64	2.6	6.9	4.33	6.07	4.37	3.72	4.18	5.02
K_2O	6.93	5.95	7.86	3.68	5.44	2.47	6.15	4.82	4.5	8.1
P_2O_5	0.58	0.58	0.57	0.47	0.47	0.37	0.42	0.28	0.25	0.11
Total	100	100	100	100	100	100	100	100	100	100
LOI	2.69	3.09	3.26	1.71	1.86	2.08	2.52	3.81	4.4	1.16
Cr	39	27	125	23	91	76	51	108	162	13
Ni	41	25	99	23	48	26	32	59	59	5
Co	20	18	20	17	15	24	13	18	22	5
Sc	9	9	11	8	11	14	8	14	16	3
V	221	217	210	160	171	152	133	120	136	34
Cu	259	229	192	120	294	93	224	90	45	69
Pb	14	6	23	17	25	17	17	29	15	19
Zn	79	93	79	76	77	103	56	108	76	66
As	9.31	4.18	4.15	2.05	2.06	18.44	8.26	9.42	17.87	212.25
Sb	<3.1	<3.13	3.11	<3.08	<3.09	<3.07	4.13	4.19	5.26	14.36
Pd	3.2	2.6	2.2	<0.5	2.9	3	1.9	2.5	2.1	<0.5
Ag	0.2	0.1	0.2	0.1	0.2	<0.1	0.1	0.1	<0.1	<0.1
Pt	1.6	1	1.7	<0.5	1.3	1	0.9	1.3	2.2	<0.5
Au	7.2	5.2	5.2	<1	2.1	1	<1	2.1	2.1	14.4
Hg	0	0	0	0	0	0	0	0	0	0
Rb	154	91	155	15	188	38	95	75	79	127
Cs	7.18	0.35	1.44	11.09	2.26	0.18	1.69	1.75	1.19	0.43
Ba	1987	1671	2507	234	437	1013	1943	1129	1187	1041
Sr	686	901	1091	548	429	1127	1276	1078	726	623
Ga	16	17	18	13	27	20	19	21	21	16
Li	63.02	20.88	16.82	81.83	21.92	15.99	32.74	17.9	18.71	3.28
Ta	0.31	0.21	0.31	0.31	0.31	0.31	0.62	0.63	0.32	0.31
Nb	<3	<3	4.2	5.1	10.3	4.1	<3	8.4	3.2	4.1
Hf	1.66	1.77	2.18	2.26	1.96	2.05	2.27	5.44	1.89	2.46
Zr	87	74	93	125	170	89	73	215	68	102
Ti	4512	4666	4091	4322	4292	4017	3708	3182	3553	1887
Y	18	22	13	26	21	20	19	23	14	16
Th	3.24	2.12	2.95	1.64	2.36	2.6	2.78	9.21	3.17	2.84
U	1.18	1.16	1.44	0.86	1.27	1.17	1.37	3.43	1.15	1.54
La	13.45	13.99	16.61	10.78	14.31	15.06	13.74	26.27	18.39	13.02
Ce	28.15	28.81	31.88	21.05	27.69	29.51	26.03	49.41	33.42	25.43
Pr	3.57	3.66	3.99	2.38	2.27	3.76	3.34	5.89	3.91	3.05
Nd	13.66	14.2	15.26	12.32	13.9	14.55	12.7	21.04	14.5	10.87
Sm	3.52	3.55	3.63	2.77	2.68	3.59	3.1	4.71	3.26	2.46
Eu	0.76	0.88	0.96	0.97	0.99	1.25	0.9	1.13	1.09	0.63
Gd	2.59	2.61	2.8	2.67	2.26	2.97	2.58	3.56	2.52	1.85
Tb	0.4	0.39	0.42	0.41	0.34	0.45	0.42	0.52	0.34	0.28
Dy	2.69	2.51	2.7	2.67	2.16	3.07	2.58	3.35	2.1	2.05
Ho	0.6	0.53	0.55	0.59	0.5	0.63	0.59	0.7	0.43	0.46
Er	1.66	1.57	1.56	1.64	1.44	1.84	1.65	1.99	1.16	1.44
Tm	0.25	0.23	0.25	0.25	0.23	0.27	0.27	0.31	0.18	0.25
Yb	1.66	1.46	1.56	1.54	1.44	1.74	1.65	2.09	1.05	1.64
Lu	0.21	0.21	0.21	0.21	0.21	0.31	0.31	0.31	0.21	0.31

CONSTRAINTS ON THE DATA

Variable mobility of the chemical components of ancient volcanics during hydrothermal alteration and low-grade regional metamorphism is now a relatively well known and documented phenomenon (Wood et al., 1976; MacLean and Kranidiotis, 1987; Gemmell and Large, 1992). The elements Ti, Zr, Y, Nb, P, and particularly the rare earth elements (REE) were essentially immobile during lower greenschist facies alteration of the Mount Read Volcanics (Crawford et al., 1992). The Burranah Formation has undergone similar alteration and so this study also concentrates on these elements. FeO_{total} and MgO abundances were also generally useful under these conditions (Crawford et al., 1992). Two samples (G95/456, G95/462) were collected from the least altered parts of the Springfield gold deposit and interpretation of these two analyses has been treated with caution.

In general, samples from the Burranah Formation show a strong negative correlation between SiO_2 contents and Ti/Zr values which suggests limited mobility of silica during metamorphism (Stolz, 1995; Berry et al., 1992). SiO_2 abundances are therefore probably close to their primary abundances and are used as a useful discriminant and fractionation indicator.

PRIMARY GEOCHEMICAL AFFINITIES

The samples collected from the Burranah Formation represent a single suite of subalkaline rocks showing typical calc-alkaline trends. They show a progressive decrease in Fe_2O_{3total} and TiO_2 with increasing fractionation (SiO_2 content),(Figs. 13 and 13A). The subalkaline nature of the suite can be further characterized in a plot of Nb/Y vs. Zr/TiO_2 values (Winchester and Floyd, 1977), (Fig. 14). In this plot the suite displays a range a compositions from basalt to rhyodacite/dacite.

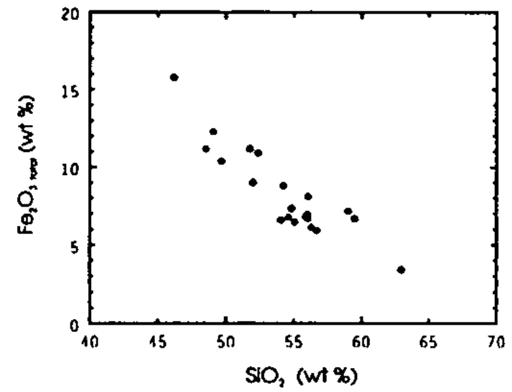


Fig.13. Total iron as Fe_2O_3 versus SiO_2 for the Burranah Formation.

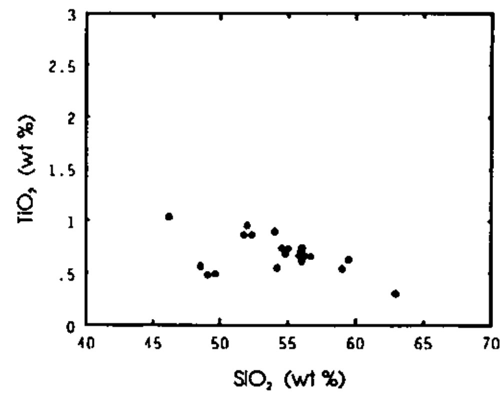


Fig. 13A. TiO2 versus SiO2 for the Burranah Formation.

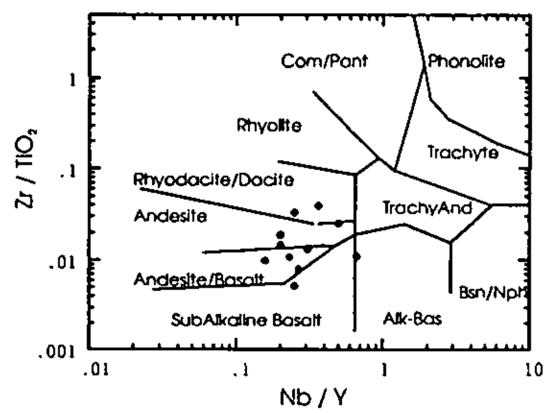


Fig. 14. Plot of Nb/Y vs. Zr/TiO_2 (after Winchester and Floyd, 1977) for the Burranah Formation. Note that 10 samples have below detection limits (3 ppm) for Nb and have not been plotted. These samples have similar values of Y, Zr, and TiO_2

The Shoshonite Association

A plot of K_2O versus SiO_2 has been used by Le Maitre (1989) to subdivide the subalkaline rock series. This plot however lacks some reliability when applied to foldbelt rocks because of the ready mobility of K_2O during metamorphism and hydrothermal alteration. Nevertheless, it has been used by Heithersay et al., (1995) for Late Ordovician volcanics from the Goonumbla area near Parkes and their results form a useful comparison for the Burranah Formation. On the K_2O versus SiO_2 plot (Fig. 15) the Burranah Formation plot on a broad linear trend across the high K calc-alkaline and shoshonite series of LeMaitre (1989). They range in composition from absarokites through shoshonites to latites. Most are shoshonites or latites and show a similar range in SiO_2 and K_2O composition as reported by Heithersay et al., (1995) for the Goonumble Volcanics near Parkes. For the purposes of this study, absarokites have <52 percent SiO_2, shoshonites 52 to 56 percent, and latites 56 to 64 percent SiO_2 (terminology modified from Gill, 1972).

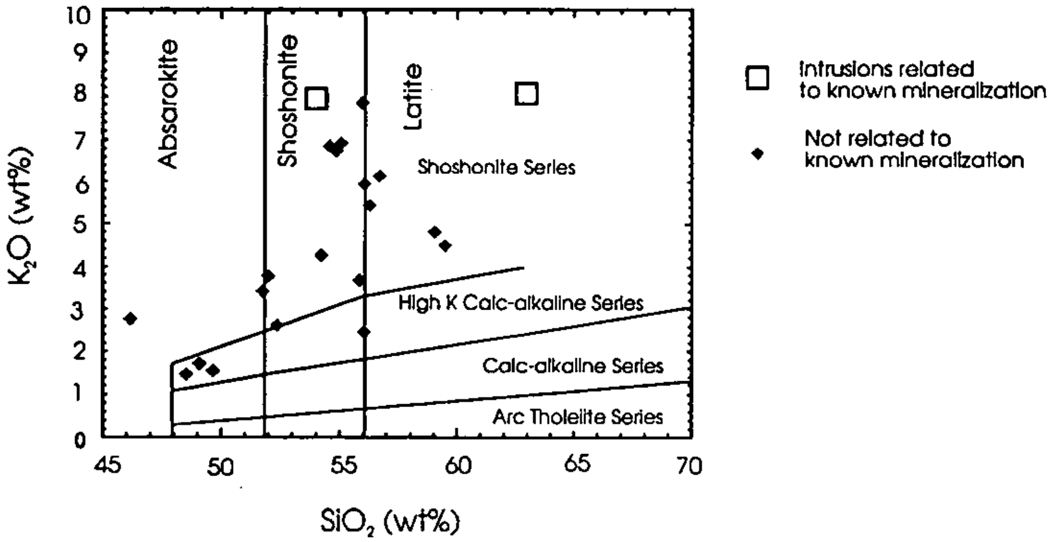


Fig. 15. K_2O versus SiO_2 (LeMaitre, 1989) for the Burranah Formation

The shoshonite association has been the subject of several reviews (Joplin et al., 1972; Morrison, 1980). The samples from the Burranah Formation are characterized by high, but variable Al_2O_3 (9.82-19.51 wt%), very high K_2O values (up to 7.86 wt% in non-mineralized samples) and high K_2O/Na_2O ratios (0.41- 3.03) which are typical of the shoshonite association (Morrison, 1980). The rocks also have enriched LILE concentrations (e.g., Ba up to 2520 ppm, Sr up to 1445 ppm), low HFSE (TiO_2 < 0.87 wt%, Zr < 216 ppm but generally < 100 ppb, Nb <10 ppm, Hf < 5.2 ppm, Y < 23 ppm) and low LREE (La <26.4 ppm, Ce < 49.7 ppm). These characteristics are best seen on spidergram plots, where elements are normalized to primoidal mantle values (Wood et al., 1979). Spider diagrams for the absarokites, shoshonites, and latites from the Burranah Formation (Fig. 16) all display a pattern of high Ba, K, Sr and P, and low Nb, Zr, Ti and Y. The patterns displayed by these plots are similar to shoshonites reported by Wyborn (1992) for the Orange area and Heithersay et al., (1995) for the Goonumbla Volcanic Complex near Parkes.

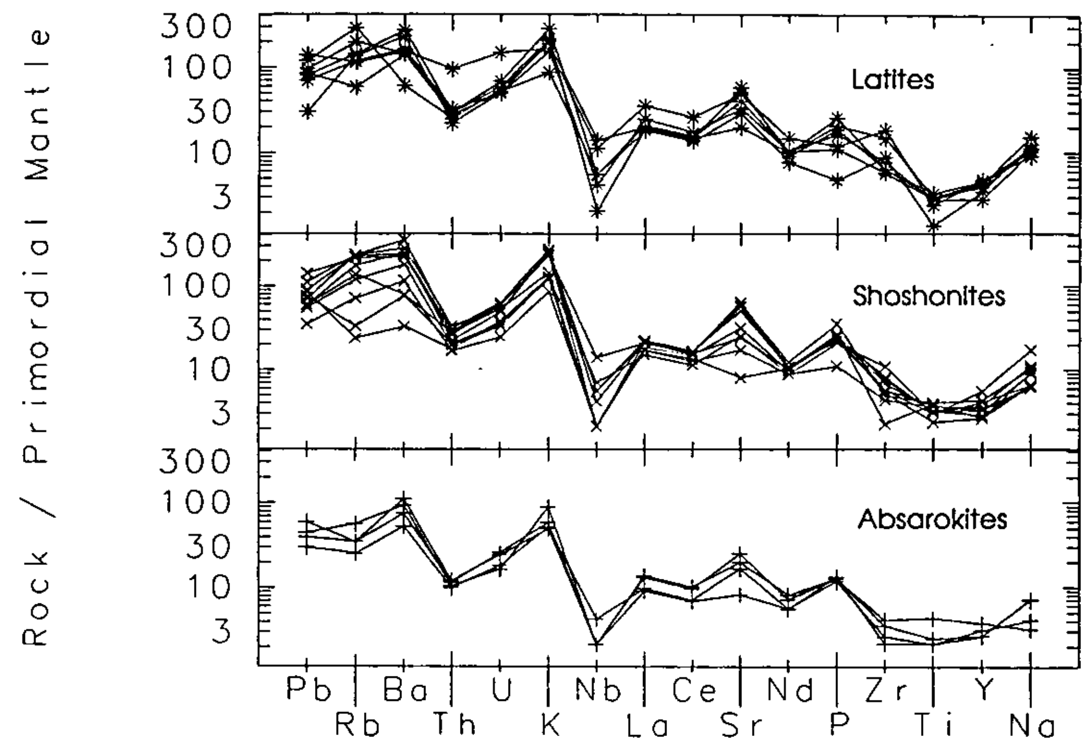


Fig. 16. Spidergram plots (mantle normalized multi-element plots, using the normalizing values of Wood et al., 1979) of the absarokites, shoshonites, and latites from the Burranah Formation. The typical shoshonite pattern of high Ba, K, Sr, and P, and the low Nb, Zr, Ti and Y is well displayed.

A feature of the Burranah Formation suite is the continuous and coherent nature of the geochemical variation from 46% SiO_2 (absarokites) to highly fractionated rocks with SiO_2 compositions of 63% (latite). This is well illustrated in plots of SiO_2 vs. TiO_2, P_2O_5, and Zr (Figs. 17A, 17B and 17C). Overall these coherent chemical variations appear to be consistent with the volcanics and intrusives of the Burranah Formation being a cogenetic suite related by low-pressure crystal fractionation. P_2O_5 increases systematically with SiO_2 to a maximum of ≈ 0.6 wt percent at 54 percent SiO_2 and decreases following apatite saturation to ≈ 0.1 wt percent in the latites.

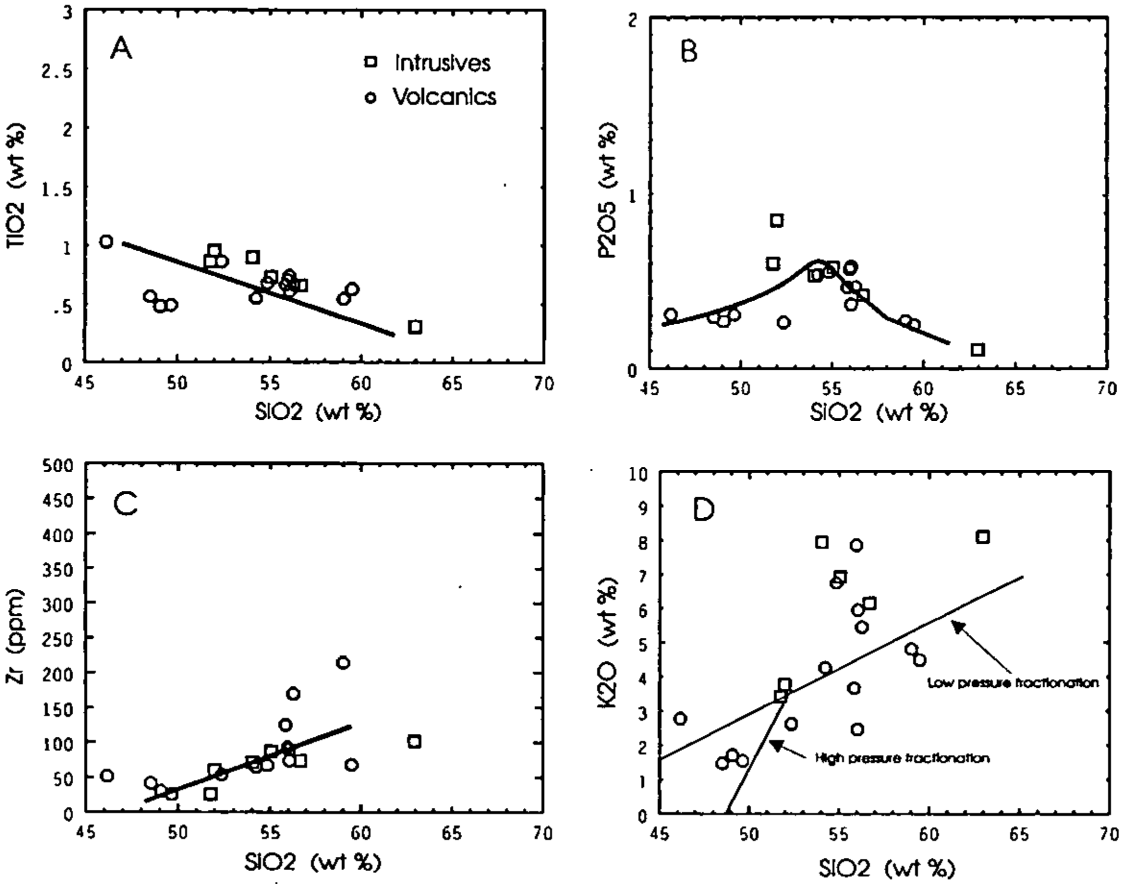


Fig. 17. Plots of SiO_2 vs. (A) TiO_2, (B) P_2O_5, (C) Zr and (D) K_2O for the Burranah Formation showing volcanic and intrusive rocks

Heithersay and Walshe (1995) proposed a model of high and low pressure fractionation for the Ordovician rocks from the Goonumbla Volcanic Complex to help explain their K_20 enrichment. Their model involves magmas ponding and fractionating at the base of the crust with variably fractionated plumes of magma ascending to shallower levels. Using data from Meene (1990) they constructed both high and low pressure fractionation trends for the variation of K_2O vs. SiO_2. These trends are reproduced in Fig. 17D together with data from the Burranah Formation. Heithersay and Walshe (1995) concluded that evolution of the Goonumbla Volcanics may have involved both high and low pressure fractionation. However, due to the smaller sample population, the trend shown for the Burranah Formation is more inconclusive.

NEODYMIUM ISOTOPE DATA

Neodymium isotope analyses were undertaken for samples of volcanic and intrusive rocks from the Burranah Formation. The purpose was to further characterise the source magma, confirm source homogeneity within the unit and also further corroborate the inferred Ordovician age. Neodymium isotopes are a useful system for this purpose in ancient volcanics because they are relatively immobile during low-grade regional metamorphism (Wood et al., 1976; Ludden et al., 1982) and they sensitively discriminate between different source rocks during melting. In addition, there is a large amount of neodymium isotope data now available for Ordovician rocks from the Lachlan Fold Belt (eg Wyborn, 1993) and from modern volcanics from different tectonic settings where contributions from different mantle and crustal source materials are commonly inferred.

The neodymium-isotope method is effectively an index of crustal residence time. Magmas derived from the long-term light-REE depleted mantle show positive initial εNd values, whereas crustally derived magmas from a source region with long-term (often > 1000 Ma) light-REE enrichment have negative εNd values. In the Lachlan Fold Belt, the crustally derived S-type granites have εNd values of -5.5 to -9.5 at 450 Ma and I-type granites have overlapping to higher values of 0 to -9 at 450 Ma (Sun and Wyborn, 1994). In contrast, Ordovician shoshonitic rocks at North Parkes in the Parkes-Narromine Volcanic Belt have εNd of +5.8 to +7.6 (Whitford et al. 1993). Wyborn (1993) analysed intrusive and extrusive shoshonites from all four volcanic belts and reported sixteen εNd values ranging from +5.7 to +8.0.

Nd isotope data for three samples from the Burranah Formation have εNd values ranging from +5.55 to +6.16 at 450 Ma (Table 3). These samples include intrusive monzodiorites and absarokite. These results are clearly within the range reported by Wyborn (1993) and also supports the conclusion from earlier geochemical data that the intrusive rocks associated with the Burranah Formation are plutonic equivalents of the volcanics.

Table 3. Nd Isotope Data for the Burranah Formation

Sample No	Rock Type	Sm (ppm)	Nd (ppm)	εNd (450Ma)	εNd (400Ma)
G95/448	Monzodiorite	2.84	13.18	+ 5.55	+ 5.13
G95/452	Monzodiorite	3.83	16.32	+ 5.71	+5.36
G95/461	Absarokite	1.86	11.98	+ 6.16	+ 5.89

The positive εNd values for the Burranah Formation reflect their derivation from a long term, LREE-depleted mantle source. The data, together with the data from Whitford et al. (1993) and Wyborn (1993), show that the Ordovician shoshonites from the Lachlan Fold Belt display a consistent isotopic signature over a very wide area from the Parkes-Narromine Volcanic Belt to the Sofala-Rockley Volcanic Belt. Whitford et el. (1993) suggest there has been little or no crustal input into this signature. However in a plot of εNd (450 Ma) versus SiO_2 (Fig. 18) for the Burranah Formation there is a general decrease in εNd values with increasing silica content. If these rocks comprise a cogenetic suite (as suggested by their geochemistry), this relationship could indicate some assimilation of continental crust during fractionation. Alternatively, it could reflect some variations in the mantle source.

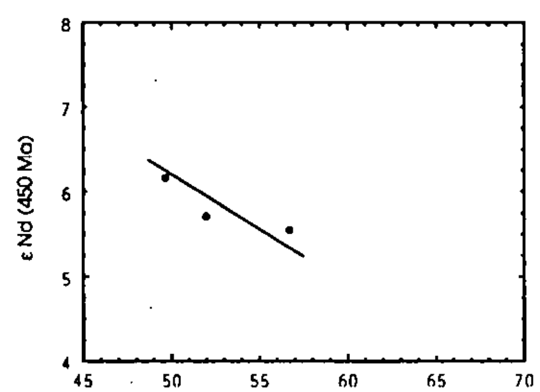


Fig. 18. Plot of εNd (450 Ma) vs. SiO_2 for the Burranah Formation

TECTONIC IMPLICATIONS

In the Lachlan Fold Belt, the Ordovician volcanics have been regarded as part of a volcanic arc or a series of arcs possibly related to west-dipping subduction (Scheibner, 1974; Webby, 1976; Pemberton and Offler, 1985; Packham, 1987). Alternatively, they may represent melting of lithospheric mantle beneath the Lachlan Fold Belt in a rifting environment as a result of asthenospheric rise in either a mantle plume or due to delamination and foundering of the lithosphere (Wyborn, 1992). In the Wyborn (1992) model, the shoshonitic character of the volcanics results from an earlier enrichment of the lithosphere, probably in an earlier subduction event.

The absarokites of Burranah Formation have low TiO2 (<1 wt % ; Fig. 13), low HFSE concentrations (including Ta, Nb, Zr), high Zr/Nb (8-18) and La/Nb values, and low Nb/Y values (Fig. 14). These abundances are typical of volcanics found in subduction-related settings and are low when compared to volcanics from divergent margin or intraplate settings. The most mafic rocks extend to relatively high MgO contents (up to 13.2 wt %) with correspondingly high Cr and Ni concentrations. The absarokites have low total REE contents (La ≈ 20-50 x chrondite) and they are characterised by light REE enrichment with relatively flat (≈10 x chrondite) heavy REE patterns (Fig. 19A). The shoshonites and latites of the Burranah Formation have slightly higher total REE concentrations and are slightly more light REE enriched.

MORB-normalised multi element patterns (Fig. 19B) for the Burranah Formation are similar to other arc volcanics such as those reported by Verbeeten et al., (1995) for the Kadavu Island Group near Fiji, showing an enrichment in LILE and a relative depletion in HFSE. They also show the characteristic negative Ta and Nb anomaly characteristic of subduction-related magmatism.

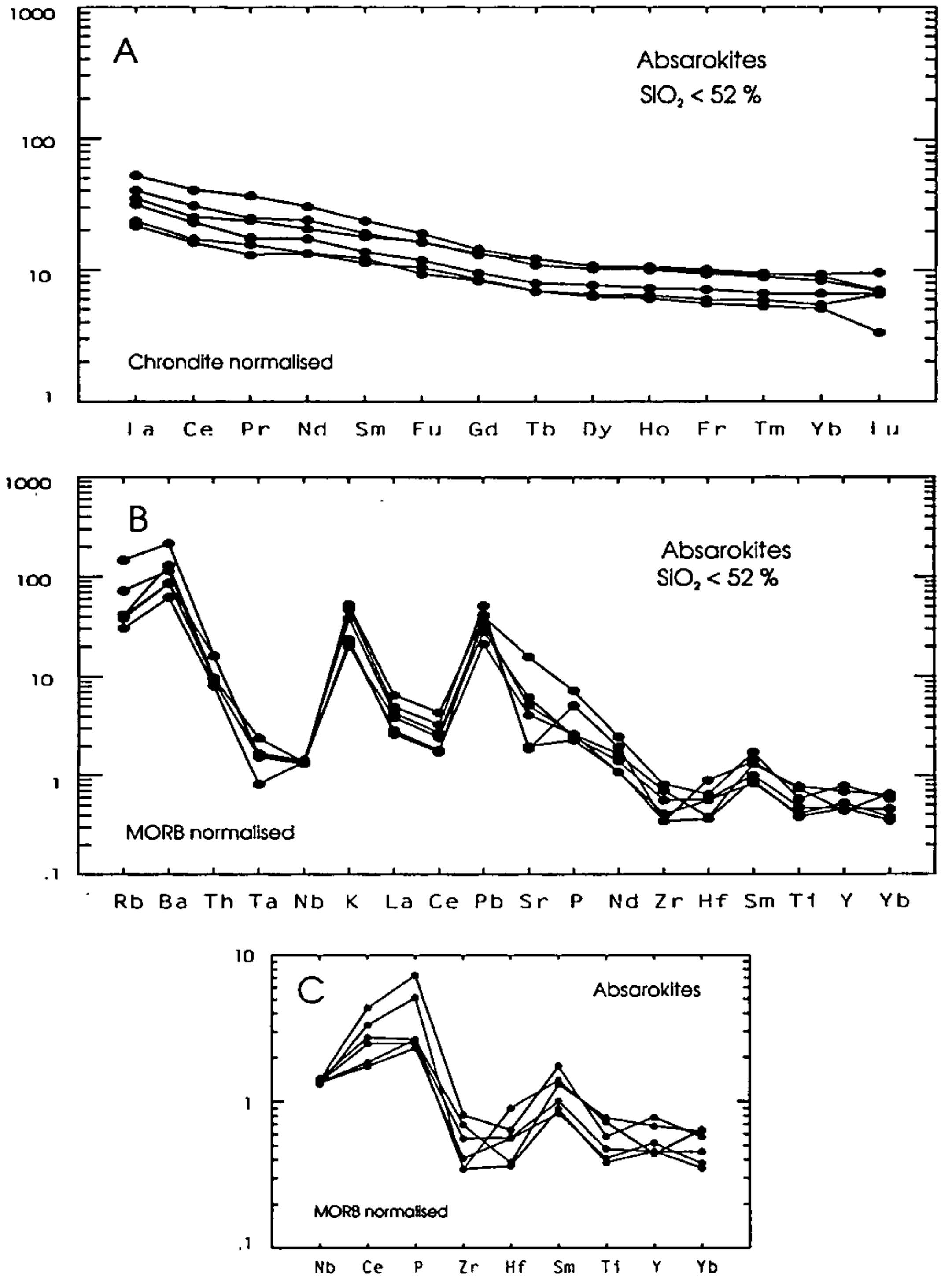


Fig. 19. A. Chrondite normalised REE plot. B. MORB normalised multi element diagram. C. MORB normalised spidergram using only immobile elements. All plots use absarokites only (SiO2 < 52 %) from Burranah Formation and all normalising values after Sun and McDonough (1989).

Ancient foldbelt volcanic rocks however, rarely have their original LILE contents. Figure 19C is a MORB-normalised spidergram that uses a subset of the full element set used in Fig. 19B. The subset elements are regarded as immobile during most low-grade alteration processes. Crawford (1994) showed using data from the Nan Suture in North Thailand and the Tasmantid seamounts Britannia and Derwent Hunter, that arc and intraplate volcanics displayed different patterns. Intraplate volcanics show an overall negative slope while subduction related volcanics show a similar negative slope with depletion in HFSE Nb, Zr, and Hf. The Burranah Formation samples (Fig. 19C) show a similar pattern to the subduction related volcanics but with slightly more elevated P.

Figure 20 is a covariation diagram adapted from Pearce (1982) that distinguishes the field of arc related basalts from those of variably enriched basalts from non-subduction settings. The Burranah Formation samples show Th enrichment at constant Ta/Yb and so plot above the mantle enrichment trend defined by MORB and intra-plate basalts. In Fig. 20 the arc basalt field is further subdivided into arc tholeiite, calc-alkaline, and shoshonitic fields. The complete suite of Burranah Formation plot mostly within the calc-alkaline field but show a fractionation trend up into the shoshonitic field. The absarokites all plot within the calc-alkaline field. The trend shown by the Burranah Formation suggests the magmas have been generated beneath thick continental crust where they have had time to cool, pond and fractionate. The magmas show characteristics which are closer to those shown by arc basalts erupted within an active continental margin (i.e., thick crust) than basalts erupted in oceanic island arcs. Basalts erupted in oceanic island arcs generally plot lower in this figure across the tholeiite/calc-alkaline boundary.

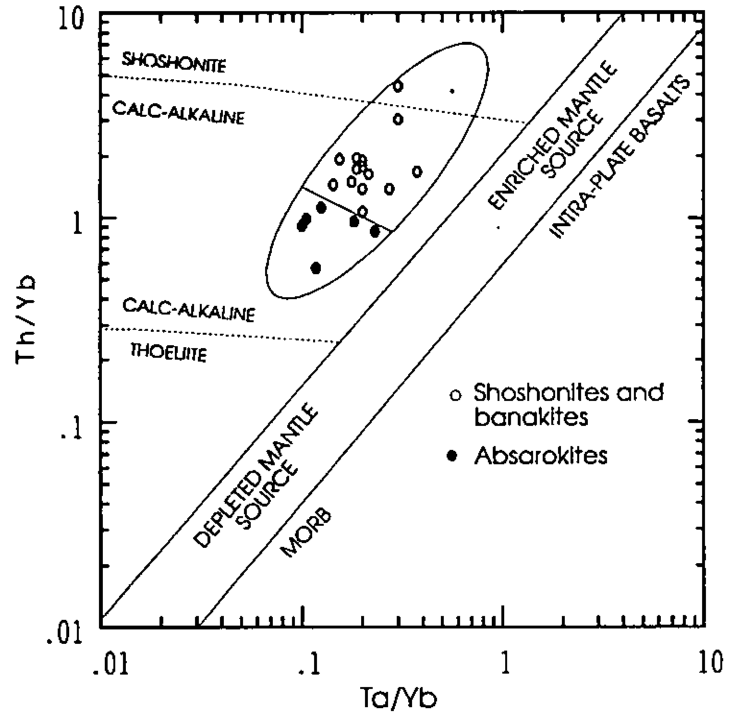


Fig. 20. Ta/Yb v. Th/Yb covariation diagram adapted from Pearce (1980) for the Burranah Volcanics

CONCLUSIONS

Geochemical data from the Burranah Formation indicate that the intrusives and volcanics comprise a coherent suite of rocks with a dominantly shoshonitic character. In MORB-normailzed plots the absorokites of the Burranah Formation display patterns typical of many modern subduction-related volcanics with a marked depletion of Ta and Nb and similar or lower abundances of the heavy REE and Ti to normal mid ocean ridge basalt. Th enrichment relative to Ta/Yb suggests the volcanics have been erupted through a relatively thick continental crust. In addition to island-arc and continental margin-arc volcanics, this geochemical signature is frequently a feature of back-arc basin basalts formed during the early stages of back-arc evolution (Stolz, 1995).

The LILE enrichment which is typical of Lachlan Fold Belt shoshonites, including the Burranah Formation, may have resulted from subduction and incorporation of oceanic crustal sediment. Alternatively it may be due to upper mantle and lower crustal processes such as zone refining (Carr, 1985) or metasomatism (Meen and Eggler, 1987).

The positive εNd (450 Ma) values obtained for the Burranah Formation shoshonites indicate a mantle source for magmatism with little or no crustal contamination. The presence of relatively high concentrations of mantle-compatible elements (i.e., MgO up to 13 wt %, Cr up to 480 ppm, Ni up to 280 ppm) further supports the interpretation that the Burranah Formation may have been erupted in a back-arc setting. Island-arc basalts generally have lower MgO (average 5-6 wt %), Cr, and Ni contents than do back-arc basin basalts, although there are some exceptions (Stolz, 1995).

MINERALIZATION

INTRODUCTION

Between 1870 and 1927 the Gulgong Gold Field produced an estimated 1 million ounces of gold. It was the deep lead deposits that supplied most of the gold production throughout the area, but some primary deposits also made significant contributions to the total gold production. The known deep leads were quickly worked out, and as most of the leads are now under cropped land, exploration for additional alluvial deposits has been restricted. This, together with the usual technical difficulties of exploring for alluvial deposits, has been a deterrent to mineral explorers. This chapter is therefore concerned only with the primary gold deposits, which generally remain more accessible for exploration and possible mining.

A total of fourteen primary gold deposits have now been located in the Mudgee-Gulgong district. Five of these deposits were previously recorded by Matson (1973) during compilation of the Dubbo 1:250,000 metallogenic sheet. The additional ten deposits have been located through searches of unpublished material held by the Geological Survey of New South Wales and with the assistance of local property owners. The deposits all comprise abandoned workings for which there are no production records. Locations of all deposits are shown on the 1:50 000 scale geological maps (Figs. 3 and 4) together with their deposit numbers.

PRIMARY DEPOSITS

The primary gold deposits of the Mudgee-Gulgong district are hosted mostly within the Burranah Formation. These deposits contain gold ± minor base metals. Deposits are also hosted in the Dungaree Volcanics and in Early Devonian diorites but these deposits generally contain gold only (Table 4).

Table 4. Primary Gold Deposits of the Mudgee-Gulgong District

Deposit no	Deposit name	Host formation	Host rock	Commodities
1	Salvation Hill	Dungaree Volcanics	Rhyodacite	Au
2	Red Hill	E. Dev. Diorite	Diorite	Au
3	Louisianna	Burranah Formation	Monzodiorite	Au, As, Zn
4	Gulgong	Burranah Formation	Monzodiorite	Au, As, Zn
5	Marina	Burranah Formation	Monzodiorite	Au, As, Zn
6	Lewis's	Burranah Formation	V'clastic sandstone	Au, Cu
7	Bells	Burranah Formation	Monzodiorite	Au, Cu, Pb, Zn, Ag, As
8	Divide 4	Burranah Formation	Monzodiorite	Au, As
9	Springfield	Burranah Formation	Monzodiorite	Au, As
10	Whales	E. Dev. Diorite	Diorite	Au, Pb, As
11	Orchard	Burranah Formation	V'clastic sandstone	Au, Cu, Pb, Zn, Ag, As
12	Box Hill	Burranah Formation	Latite	Au
13	Belinfante	E. Dev. Diorite	Diorite	Au
14	Royal George	Dungaree Volcanics	Rhyodacite	Au

DEPOSITS HOSTED IN THE BURRANAH FORMATION

Springfield Deposit (Deposit no. 9)

The Springfield deposit is located about 10 km south of Gulgong in the headwaters of the historic Springfield deep lead. The deposit was not recorded by Matson (1973) and is first mentioned in literature in a report by Endeavour Resources Limited (1981). There are no production records available for the deposit, but like most of the primary deposits in the district, production was probably small with high grades. Subsequent work on the deposit by International Mining Corporation (IMC) NL (Hawley, 1988) culminated in a gold resource estimate of 1.4 million tonnes at 1.4 g/t Au. Hawley considered the deposit to have a metasomatic origin. Additional drilling by Newmont Australia Limited (Holliday, 1990) in joint venture with IMC did not improve the overall tenor of the deposit. Newmont viewed the deposit as an encouraging new occurrence of porphyry style mineralization in an area that historically produced large amounts of alluvial gold.

At the surface, the Springfield deposit is expressed as a series of collapsed shafts located on two north-northwesterly trending parallel quartz veins about 50m apart. The quartz veins have a thickness of about 30 cm and are located within a north-south elongate monzodiorite intrusive. The monzodiorite intrudes crystal lithic tuffs and volcaniclastic siltstones. Brecciation and shearing are locally developed along the western contact. The eastern contact of the intrusive is obscured by alluvium.

Alteration is variable throughout the deposit but is generally propylitic to phyllic and mostly confined to the monzodiorite. Common alteration minerals include chlorite, epidote, sericite and calcite. Arsenopyrite and pyrite are the dominant sulphides with minor chalcopyrite. Gold occurs as coatings on arsenopyrite which in many cases, surrounds the pyrite. Gold also occurs in solid solution or as free gold within the pyrite or arsenopyrite (Hawley, 1988). The sulphides and gold occur in stockwork veins or disseminations in the altered monzodiorite

Drilling of the deposit by Newmont (Holliday, 1990), indicates the monzodiorite body is west dipping. Alteration in the eastern or footwall side of the intrusive is more intense than in the western or hangingwall side which is largely unaltered. The density of quartz veining also increases towards the east and becomes a stockwork system on the footwall side.

The Springfield deposit is located within a zone of higher strain between the Mount Galambine Fault and the Magpie Hill Fault. These faults define a north-south-trending zone up to 1.5 km wide that has been subject to dextral strike-slip deformation. On the regional magnetic data, the Springfield deposit is interpreted to lie on a north-northwest trending (340^0) dextral fault between the Mount Galambine Fault and the Magpie Hill Fault. To the east of the deposit is a north-trending magnetic lineament. A north-east trending sinistral fault truncates the northern end of the deposit (Fig. 21).

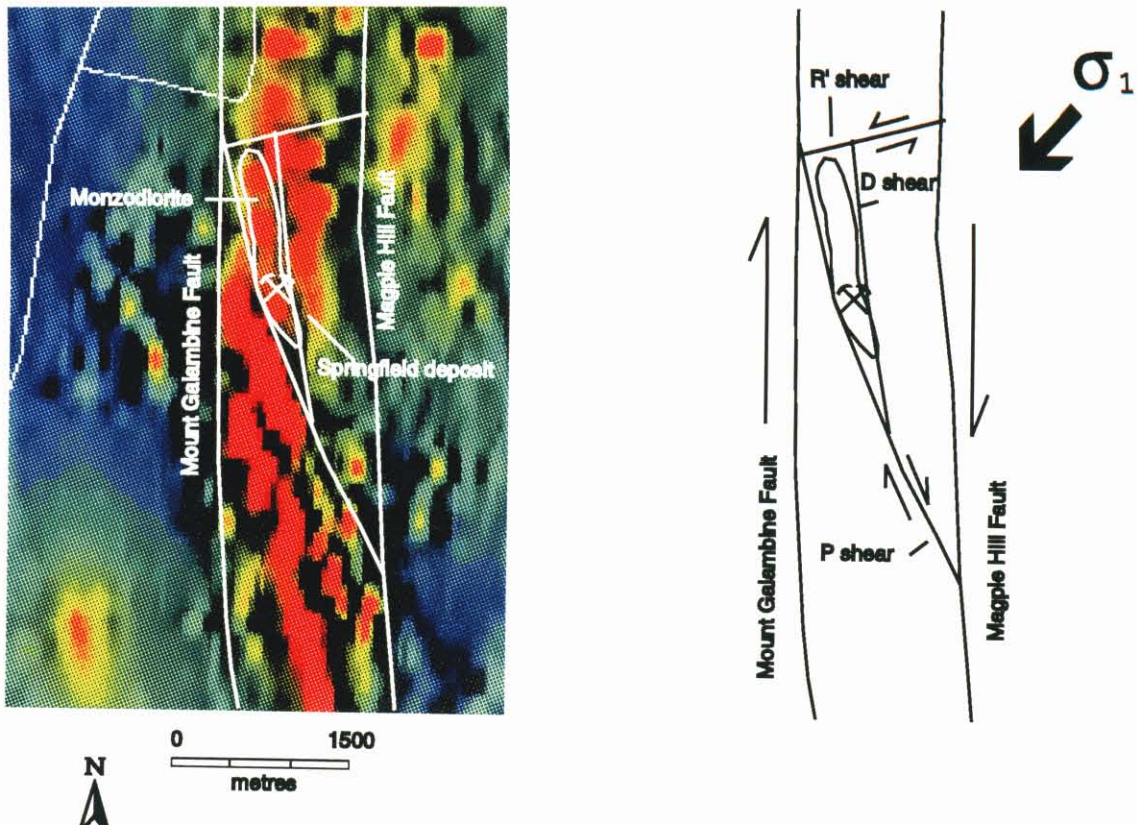


Fig. 21 Interpretation of the first vertical derivative RTP magnetic image for the Springfield deposit area

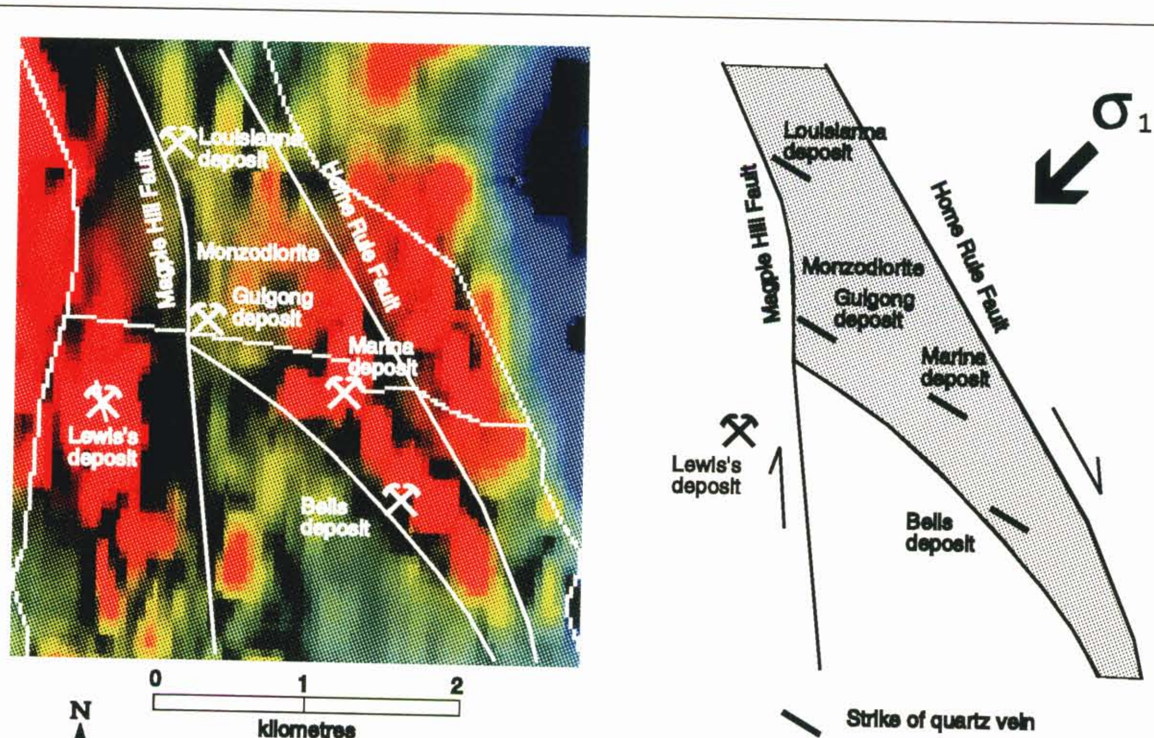


Fig. 22 Interpretation of the first vertical derivative RTP magnetic image for Gulgong group of deposits

The character of the mineralization at the Springfield deposit is consistent with mesothermal vein-style mineralization controlled by brittle deformation of a structurally competent body, i.e., the monzodiorite. The geometry of the fault system is similar to the theoretically predicted shear geometry derived from experimental studies by Tchalenko (1968) for isotropic materials deformed by bulk simple shear. Using the nomenclature of Tchalenko (1968) the northwest trending fault corrosponds to an oblique (P) shear and the north trending lineament is a central (D) shear. Maximum dilatancy on the central (D) shear has led to increased fluid flow on the eastern side of the intrusive body and resulted in the increased veining and alteration on this side of the deposit.

The Louisianna, Gulgong, Mariner, and Bells Deposits (Deposit no's. 3, 4, 5, 7)

The Louisianna, Gulgong, Mariner and Bells deposits are all located in monzodiorite about 3 to 5 km southeast of Gulgong. They were the first hard rock mines to be worked in the district and grades averaged about 20 g/t Au (Matson, 1973).

The four deposits consist of vertical to steeply dipping quartz veins up to 0.5m in thickness that generally strike 320^0. Individual deposits have strike lengths of up to 300 m and were interpreted by Matson (1973) to be hosted within a single acid intrusive body thought to be related to the Gulgong Granite. Petrological and whole rock geochemical data indicate the intrusion is monzodioritic with a clear affinity with the Burranah Formation. The monzodiorite body is located between the Magpie Hill Fault and the Home Rule Fault and is relatively magnetic. The body becomes slightly less magnetic, and perhaps more altered, on its eastern side adjacent to the Magpie Hill Fault (Fig. 22).

The veins at the Louisianna, Gulgong and Marina deposits are laminated or composite laminated and massive quartz veins with accessory sphalerite, arsenopyrite and gold. Limited sericite alteration of the wall rocks occurs within millimeters of the veins, and arsenopyrite occurs locally as dissemination of coarse-grained euhedral crystals close to the vein. Small epidote veins are also common.

At the Bells deposit the rocks show some evidence of shearing. Malachite and azurite are present along joints and fractures, and one oxidised (limonitic) sample showed a trace of gold. A sample from a small pit at this deposit assayed 13.9% copper, 0.74% lead, 0.35% zinc, 7 ppm gold, 94 ppm silver, and 870 ppm arsenic.

Mineralization in these four deposits consists of mesothermal veins preferentially hosted in the monzodiorite intrusive in a zone of high strain between the Magpie Hill Fault and the Home Rule Fault. The veins in these deposits trend at a low angle to both faults and have developed in a P-shear (using the nomanclature of Tchalenko, 1968) during regional deformation (Fig. 22). Mineralization being preferentially controlled by the structurally more competent monzodiorite intrusive.

Orchard Deposit (Deposit no. 11)

At the Orchard deposit there are three small pits which trend north-northeasterly over a strike length of 150 m within tuffaceous sandstone. There is little evidence to suggest the deposit was worked to any considerable depth. The rocks show evidence of minor shearing and weak brecciation. Sericite and carbonate alteration are common and malachite and azurite occur along fractures and joint planes. Gossanous rocks near the pits are highly siliceous with rare inclusions of chalcopyrite. The gossan material returned assay results of 10.3% copper, 3 100 ppm lead, 2 400 ppm zinc, 0.4 ppm gold, 11 ppm silver and 1180 ppm arsenic.

Box Hill Deposit (Deposit no. 12)

The Box Hill Deposit consists of a 450 m long, northeast-trending zone of altered coherent volcanic rocks of latite composition. The alteration is developed over a width of about 150 m and is confined to the steeply west dipping unit of latite. Moderate to weak carbonation, silicification, and veining are present throughout the zone with two sub parallel zones of intense alteration developed over widths of 10 m within the latite. Weak mineralization (0.4 ppm Au, 130 ppm As, 95 ppm Cu) is associated with the altered latite.

The only obvious control on mineralization at the Box Hill deposit is the host rock. Alteration and mineralization are confined to the latite unit between adjacent units of volcaniclastic sandstone.

Lewis's Deposit (Deposit no. 6)

At the Lewis's deposit there are two partly collapsed shafts approximately 25m apart and two small prospecting pits. The shafts are located on a small north-trending (345^0) fault between the Mount Galambine Fault and the Magpie Hill Fault. The deposit is hosted within volcaniclastic sandstone but the magnetic data indicate the presence of intrusive monzodiorite or coherent volcanics at depth (Fig. 22). Local shearing is developed along the north-trending fault with common albite and sericite alteration. A norteast-trending fault is exposed in the pit and carries some secondary copper minerals. Malachite, azurite and chrysocolla are common minerals in joints and fractures.

Mineralization at the Lewis's deposit is controlled by a similar set of structures to those at the Springfield deposit (deposit no. 9). The main fault controlling mineralization at Lewis's trends at a low angle to the Mount Galambine Fault and the Magpie Hill Fault and corrosponds to a P-shear (using the nomenclature of Tchalenko, 1968). At this deposit, the northeast-trending fault corrosponds to an R'-type fault in the Riedel model (Tchalenko, 1968) and is also mineralized.

DEPOSITS HOSTED IN THE DUNGAREE VOLCANICS

Royal George Deposit (Deposit no.14)

The Royal George deposit is located about 1.5 km south of Mount Galambine within the Dungaree Volcanics. It occurs about 700 m above the contact with the Burranah Formation and is confined to a 100 m thick coherent volcanic (rhyodacite) unit. The deposit was previously recorded by Matson (1973) but with incorrect host rock and vein orientation data. The deposit was worked from 1870 to 1899 and had several high-grade shoots that contained from 92 to 122 g/t Au. Average grade and total production figures are not available.

The deposit contains of a set of three tabular parallel quartz veins up to 0.5m thick trending 060^0 and spaced 70 m and 120 m apart. The central vein appears to have been the most productive and has a total of five shafts sunk along its length. All veins dip to the southeast at angles between 40^0 to 60^0. Vein material from the dumps located on the central line of workings have a laminated appearance and occasionally exhibit crystal lined vughs. Sulphides present include chalcopyrite, galena, pyrite and arsenopyrite.

The vein textures indicate they were formed as open space fillings under high fluctuating fluid pressure. Cleavage developed in volcaniclastic units to the east and west of the deposit strikes 330^0 and dips steeply to the west. The veins at the Royal George deposit are therefore developed perpendicular to the regional cleavage and essentially parallel to the maximum principal stress (NE-SW). Mesothermal vein-style mineralization at the Royal George deposit developed as tension veins confined to the structurally more competent rhyodacitic unit within the Dungaree Volcanics.

Salvation Hill (Deposit no. 1)

Gold mineralisation at Salvation Hill occurs in a porphyritic rhyodacite that has been fractured, brecciated, veined, hydrothermally altered and pyritised, as well as contact metamorphosed by the nearby Gulgong Granite. Hydrothermal alteration comprises sericite ± silica, chlorite, biotite and K-feldspar. Little quartz veining is evident in outcrop. The main load at Salvation Hill trends northeasterly, with a northwesterly dip. The length of mineralisation and total production has not been recorded, but the width of the lode ranges up to 12.2 m (Matson, 1973). Sulphides (pyrite and arsenopyrite) and very minor base metals are located in probable tension veins as fine -grained disseminations, clusters or veinlets.

The Salvation Hill deposit is located about 500 m to the northwest of a prominent east northeast-trending lineament that is obvious on the regional magnetic data. This lineament also comprises the southeastern margin of the Gulgong Granite. The trend of mineralization in the deposit is essentially perpendicular to the regional and local cleavage. The structural competency of the porphyritic rhyodacite may have been a factor in localising the tension veins at this deposit.

DEPOSITS HOSTED IN EARLY DEVONIAN DIORITES

Whales Deposit (Deposit no. 10)

The Whales deposit is hosted in a small, circular non-magnetic diorite that intrudes a mixed volcanic and volcaniclastic sequence of the Burranah Formation.

The deposit contains of a number of collapsed shafts that strike in a northerly direction and are associated with pervasive silica and carbonate alteration. Breccia is present on the old dumps and consists of randomly oriented fragments of chloritically altered wall rock and quartz vein fragments in a quartz matrix. Arsenopyrite, pyrite, and galena occur in narrow chloritic zones adjacent to the quartz veins. The eastern side of the diorite intrusive is transected by several northeast trending sinistral faults.

The Whales deposit is localised in a diorite intrusive located between two northwest-trending dextral faults (Fig. 23). These faults define a 1 km wide zone that has been subjected to dextral strike-slip deformation. The north-trending mineralization at this deposits is consistent with the interpretation of brittle deformation and mineralization of the structurally more competent diorite in an R-type shear in the Riedel model (Tchalenko, 1968). In this model, the northeast-trending sinistral faults that cut the eastern half of the intrusive are interpreted as R'-type faults in the Riedel model (Tchalenko, 1968).

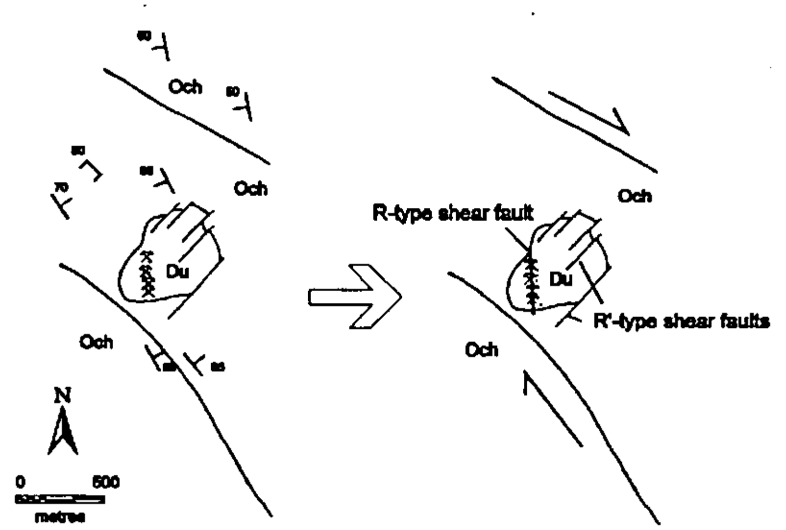


Fig. 23 Interpreted structural setting of the Whales deposit

Red Hill Deposit (Deposit no. 2)

The Red Hill Deposit is located adjacent to the Magpie Hill Fault within the town boundary of Gulgong. It was the site of the original discovery of gold in the Gulgong district. The mine site has now been rehabilitated and the only available descriptions of the workings are those given by Jones (1940).

Mineralization at the Red Hill Mine occurs in a diorite that has intruded the Burranah Formation. The diorite does not outcrop at the mine site but Jones (1940) describes 'highly altered claystones which have been intruded by dykes and masses of diorite.' Quartz veins are described as small and irregular and traversing the diorite in all directions. A 'persistent quartz reef' that varies in thickness from 10 cm to 70 cm trends north-south and dips to the east. Free gold occurs in the quartz veins and in the altered country rocks for up to 5 m from the veins (Jones, 1940).

The diorite body at the Red Hill deposit is reasonably magnetic and well defined by the airborne magnetic data. The diorite becomes less magnetic, perhaps due to alteration, along its eastern margin adjacent to the Magpie Hill Fault. Outcrops of the diorite have been located to the west and southwest of the town. Whole rock geochemical data indicate that the diorite is distinctive from the intrusives of the Burranah Formation. This data, together with the observations of Jones (1940), supports the interpretation that the intrusive is one of the younger, probably Early Devonian suite.

The Red Hill Deposit is localised on the eastern side of the diorite body adjacent to the Magpie Hill Fault (Fig. 4). Dextral movement on this fault has been interpreted to the south of this area and may have also been responsible for brittle deformation of the more competent diorite adjacent to the fault. The fractured and brecciated diorite has provided a fluid pathways for the development of the stockwork and sheeted vein system.

Belinfante Deposit (Deposit no. 13)

The Belinfante Deposit is located about 1.5 km west of Mount Galambine within a west-dipping sequence of the Dungaree Volcanics and in the footwall of the Mudgee Fault (Fig. 4). The prospect occurs within an elongate north-south diorite intrusive that is concordant with the host volcanics. The central area of the intrusive is covered with alluvium leaving northern and southern areas of outcrop. Numerous old workings are located within the diorite body, clustered toward the southern end of the northern outcrop area.

The diorite body is essentially non-magnetic but its extent is well defined by the more magnetic hornfelsed volcaniclastics. The magnetic data indicate the diorite may be folded into a synform with a faulted eastern limb (Fig. 4).

Alteration at the Belinfante deposit corresponds closely to the outcrop of the diorite intrusive. The alteration zone is characterised by pervasive carbonate alteration with lesser silicification and disseminated pyrite. The most intense alteration occurs on the western side of the diorite in the area of the old workings and is accompanied by quartz-carbonate-pyrite stockworks.

At the Belinfante Deposit, the diorite intrusive has been the preferred lithology for alteration and mineralization. A strong competency contrast exists between the diorite and the enclosing volcaniclastic lithologies of the Dungaree Volcanics. The location of the stockwork veining is consistent with brittle deformation of the diorite, and fluid movement into this area during D2 movement on the Mudgee Fault and the formation of the footwall syncline.

LEAD ISOTOPE DATA

The use of lead isotopes as a discriminator in mineral exploration is based on a detailed understanding of the relationships between isotopic signatures and the age and nature of all mineralizing events in a particular tectonic domain. Carr et al., (1995) present an objective method of relating mineral occurrences to tectonic events in the Lachlan Fold Belt based on a study of over 100 deposits. In this study, isotope data was integrated with geochronological data and detailed geology to define a plumbotectonic framework that can be used to predict the likely metallogenic association, and thus potential economic significance, of sulphide mineralization.

Carr et al., (1995) published a lead isotope ratio value for the Springfield deposit (deposit no. 9) but attempted to interpret the value in the context of the Early Devonian age previously assigned to the Burranah Formation.

To supplement the reinterpretation of this data, a sample of galena from quartz vein material from the Orchard deposit was analysed at the CSIRO (North Ryde) for its lead isotopic compositions. The results of the analysis together with the published data of Carr et al., (1995) are shown in Table 5.

Table 5. Lead Isotope Compositions of Samples from the Burranah Formation

Deposit	Sample	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	LFB Model age (Ma)	Source
Springfield	D9	18.30	15.52	38.00	365	Carr et al., (1995)
Orchard	GUJW6	18.25	15.55	38.05	370	This study

The lead isotope data has been plotted with data from Carr et al. (1995) for deposits from other Ordovician shoshonitic volcanics in the Parkes-Narromine belt in the Lachlan Fold Belt (Fig. 24). On this figure the Peak Hill, Lake Cowal, and Endeavour group of deposits all plot on the mantle mixing line. The data from the Springfield and the Orchard deposits have slightly higher $^{207}Pb/^{204}Pb$ ratios and plot with the London-Victoria, Dayspring, Mt Morgan and Ben Nevis group of deposits. This group of deposits deviates from the mantle mixing line and show lead isotope compositions that are intermediate between crustal and mantle sources. The London-Victoria, Dayspring, Mt Morgan and Ben Nevis deposits are all structurally controlled vein gold deposits with hydrothermal activity regarded as syn- or postdeformational (Clark et al., 1990). The smaller deposits in this group, such as the Ben Nevis and Day Spring show the most crustal contamination while the larger deposits such as London Victoria have the least contamination.

The small, though significant, crustal component of lead in the Springfield and Orchard deposits, and their LFB model ages is consistent with mixing in response to hydrothermal events (metamorphic) rather than Ordovician processes. The mantle lead was probably derived from leaching of the Ordovician intrusives within the middle to upper crust rather than being directly plumbed from the mantle. This was mixed with higher $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratio crustal lead derived from the volcaniclastic dominated wall rocks.

The lead isotopic signatures of sulphide mineralization from the major porphyry and epithermal copper $\pm$ gold deposits hosted within Ordovician shoshonites (eg, the Endeavour group of deposits) all plot on the mantle mixing line. Carr et al., (1995) postulated that the position of each deposit along this line is an indication of the timing of metallogenesis within the Ordovician magmatic cycle, and possibly also the degree of mixing of melts from a more primitive asthenosphere and a more enriched lithosphere, potentially fertile for copper and gold. Samples which plot on the mantle mixing line and have high $^{206}Pb/^{204}Pb$ ratios are considered to have the best chance of representing a large metallogenic event. The mixed mantle and crustal signature of the lead in the Springfield and Orchard deposits suggests that these deposits, and perhaps the Burranah Formation in general, may have limited tonnage potential.

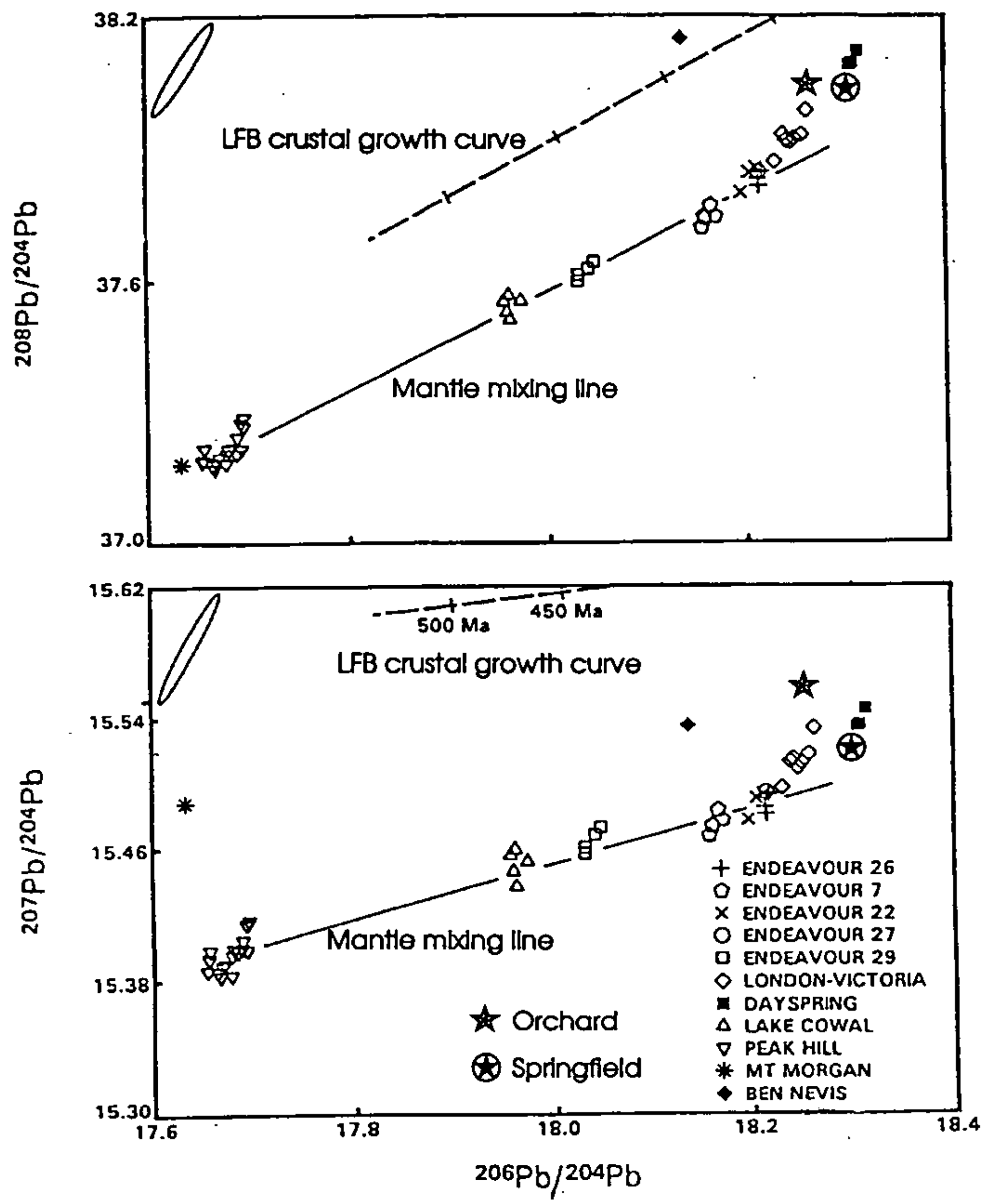


Fig. 24 Lead isotope ratio plots of sulphide mineralization from deposits hosted in the Burranah Formation. Figure modified from Carr et al., (1995).

SULPHUR ISOTOPE GEOCHEMISTRY

The sulphide minerals arsenopyrite and pyrite are ubiquitously associated with gold in many of the deposits hosted in the Burranah Formation. The sulphur isotopic compositions of these minerals therefore provide a means to evaluate possible sources of sulphur and assist the overall genetic interpretation of these deposits.

In the Springfield deposit, arsenopyrite occurs as large euhedral crystals. Eight arsenopyrite samples were hand drilled from altered monzodiorite from this deposit and the powders collected for analyses on the stable isotope mass spectrometer at the University of Tasmania. The $\delta^{34}S$ percentage values obtained from the samples are shown in Table 6.

Table 6. Sulphur Isotope Data from the Springfield Deposit

Sample no.	Alteration	Mineral	$\delta^{34}S$ (%)
GUJW0027a	Quartz/sericite	Arsenopyrite	15.6
GUJW0027b	Quartz/sericite	Arsenopyrite	15.6
GUJW0027c	Quartz/sericite	Arsenopyrite	16.0
GUJW0027d	Quartz/sericite	Arsenopyrite	15.8
GUJW0027e	Quartz/sericite	Arsenopyrite	15.8
GUJW0027f	Quartz/sericite	Arsenopyrite	16.1
GUJW0027g	Quartz/sericite	Arsenopyrite	15.9
GUJW0027h	Quartz/sericite	Arsenopyrite	15.7

Ohmoto and Rye (1979), stress that it is difficult to characterize the sulphur isotopic values of all potential reservoirs, because small changes in temperature, pH, and oxygen activity can induce profound changes in the sulphur isotopic values of indigenous or derived sulphur-bearing species. Significant fractionations can potentially occur at the fluid and sulphur source, during fluid migration and transport, and at the site of precipitation during rock fluid interaction. Given the specific environment of the Springfield mineralization however, the most likely sources of sulphur, in terms of size and availability of reservoirs, include direct derivation from mantle fluids, leaching of primary and secondary sulphide minerals, and seawater sulphate.

The $\delta^{34}S$ value of Late Ordovician seawater sulphate is about 28% (Claypool et al ., 1980). Fractionation values for bacterial reduction of seawater vary from as high as 40% in open systems to very low values in a closed system such as a deep marine environment. In the latter case, sulphate reduction would cause the $\delta^{34}S$ values of reduced sulphur to remain close to that of the contemporaneous seawater sulphate. Syngenetic sulphides with large positive values would be incorporated into volcaniclastic and volcanogenic deposits of the Burranah Formation in such a closed system.

Primary sulphides of the Burranah Formation volcanics and intrusives would have a $\delta^{34}S$ value close to that of magmatic sulphur. Hydrothermal fluids that obtained sulphur by decomposition of sulphides in igneous rocks would have $\delta^{34}S$ values close to those of the magmatic fluids (Ohmoto and Rye, 1979).

The $\delta^{34}S$ values of the hydrothermal arsenopyrites from Springfield define a single population with a narrow range between 15.6 and 16.1%. These values are inconsistent with a direct magmatic contribution but possible sources for the sulphur include the following:

1. Seawater sulphate reduced in a partial closed system with a $\Delta S \approx -12\%$
2. Mixing during metamorphism and deformation of magamatic sulphur in the coherent volcanics and intrusives with seawater sulphate in the volcaniclastics and volcanoclastics.

Option (2) is the preferred option and is consistent with the interpretation of the lead isotopic data that also indicates that mixing, in response to hydrothermal events (metamorphic) was important.

DEPOSITIONAL MODEL

Host Rocks

Primary gold mineralization is hosted in rocks which range in age from Late Ordovician (Burranah Formation) to Early Devonian (diorites). Within these units, the structurally more competent lithologies are preferentially mineralized. These include diorites and monzodiorite intrusives and coherent volcanic rocks.

The host rocks have been metamorphosed to lower greenschist facies grade during regional deformation. Hydrothermal alteration associated with mineralization generally comprises a propylitic to phyllic assemblage of carbonate, chlorite, sericite, and quartz. These alteration assemblages suggest mesothermal temperatures of emplacement for the mineralization of about 200^0C to 250^0C. In many cases, hydrothermal alteration has been magnetite destructive and produced magnetic lows in areas of mineralization.

Structural Setting

Mineralization is mostly confined to a zone of higher regional strain between the Mudgee Fault and the Home Rule Fault. Within this zone gold mineralization occurs primarily in dilational and shear type extension veins. As such, the deposits are structurally controlled and directly related to fault systems. The distribution of gold mineralization is a function of the variably rheology of the host rock succession. The development of extension veins requires that the rock deform in a brittle manner.

The orientation of the faults, shear zones and veins within the district are consistant with those predicted by a dominantly dextral Reidel shear model.

Fluid Sources

The lead and sulphur isotope data are consistent with the interpretation that the ore-forming fluids are of metamorphic origin and are derived, along with the gold, from the host rock sequence.

Timing of Mineralization.

Similar styles of structurally controlled gold deposits are present in host rocks of the Late Ordovician Burranah Formation, the Late Silurian Dungaree Volcanics and the Early Devonian diorites. The ubiquitous and systematic association of the mineralization with faults and shear zones, and evidence regarding the timing and formation of mineralisation from lead isotope studies, suggests that orebodies are syndeformational, metahydrothermal in origin. The style and nature of the deformation within the area are consistent with the regional Early Carboniferous deformation responsible for the majority of folding, thrusting and cleavage formation in the northeastern Lachlan fold Belt. The age of the mineralization is regarded as Early Carboniferous.

CONCLUSIONS

STRATIGRAPHY

- The Palaeozoic stratigraphy of the Mudgee-Gulgong district has been substantially modified. The district now essentially constitutes a west younging sequence of Late Ordovician volcanics and volcaniclastics (Burranah Formation, Coomber Formation), Late Silurian shelf rocks (Dungaree Volcanics), and Late Silurian turbidites (Chesleigh Formation). Early Devonian diorites intrude both Ordovician and Silurian units. Early Devonian siliclastics (Carwell Creek Formation) dominate much of the southeastern part of the area and Middle Carboniferous granitoids occur in the north, northeast and east.

STRUCTURE

- The district has been subject to one dominant Early Carboniferous deformation that produced meridional to northwest-trending folds, cleavage, thrust faults and oblique-slip faults. A zone of higher regional strain is developed within the Burranah Formation and Dungaree Volcanics and hosts much of the mineralization.

GEOPHYSICS

- Interpretation of high resolution geophysical data has greatly aided the mapping and interpretation of this area. First derivative TMI and RTP images provide useful local and regional scale structural and lithological data. The red radiometric response of the Ordovician volcanics is a good indicator of units with shoshonitic geochemistry.

- The interpretation of magnetic data does not indicate the presence of any complex patterns characteristic of sub-volcanic systems that may potentially host a large tonnage porphyry-type system within the Burranah Formation.

GEOCHEMISTRY

- Volcanic and intrusive rocks of the Burranah Formation comprise a coherent calc-alkaline suite with a dominantly shoshonite character. In MORB-normalized plots they display patterns typical of many modern subduction-related volcanics with a marked depletion of Ta and Nb and similar or lower abundances of the heavy REE and Ti. Positive εNd values indicate a mantle source for the shoshonites with little or no crustal contamination.

MINERALIZATION

- Primary gold mineralization is characterised by small tonnage deposits that are structurally controlled. The mineralization is mostly located within a zone of higher regional strain between the Mudgee Fault and the Home Rule Fault. Within this zone, gold mineralization occurs primarily in dilational and shear extension veins in the structurally more competent units of the Burranah Formation and the Dungaree Volcanics and in Early Devonian diorites. The mineralization is generally restricted to areas of brittle deformation within the more competent units.

- The orientation of the faults, shear zones and veins are consistent with those predicted by a dominantly dextral Tchalenko shear model.

- Alteration assemblages are commonly propylitic to phyllic and indicate mesothermal temperatures of emplacement. Lead and sulphur isotope data are consistent with the interpretation that the ore-forming fluids are metamorphic in origin and are derived, along with the gold, from the host rock sequence.

- The mineralization is syndeformational metahydrothermal in origin and was formed during the main regional Early Carboniferous deformation. This deformation was also responsible for the majority of folding, thrusting and cleavage formation in the northeastern Lachlan Fold Belt.

- The Burranah Formation has the potential for additional, but probably small tonnage, structurally hosted gold deposits. Coherent volcanics or monzodiorite intrusives may constitute larger tonnage host rock targets than volcaniclastic or sedimentary units. Geophysical data indicate that the monzodiorite intrusive associated with the Gulgong group of deposits has considerable subsurface extent and may constitute a high priority exploration target.

- Geological mapping, together with the interpretation of high resolution geophysical data indicate there is little, if any, potential for the development of a large tonnage porphyry-type system within the Burranah Formation. This conclusion is supported by lead isotope data which indicate a limited metallogenic episode in the Early Carboniferous.

- The Dungaree Volcanics are a felsic to intermediate volcanic unit deposited in a shelf or slope setting. The unit constitutes an important exploration target for structurally controlled gold deposits and for VHMS style mineralization.

- Early Devonian intrusive diorite units located adjacent to major structures form an additional and important exploration target. Although no production figures are available for any deposits in the district, the Early Devonian diorite hosted gold deposit at Red Hill was probably one of the largest deposits. Potential exits throughout the district for additional intrusives to be located.

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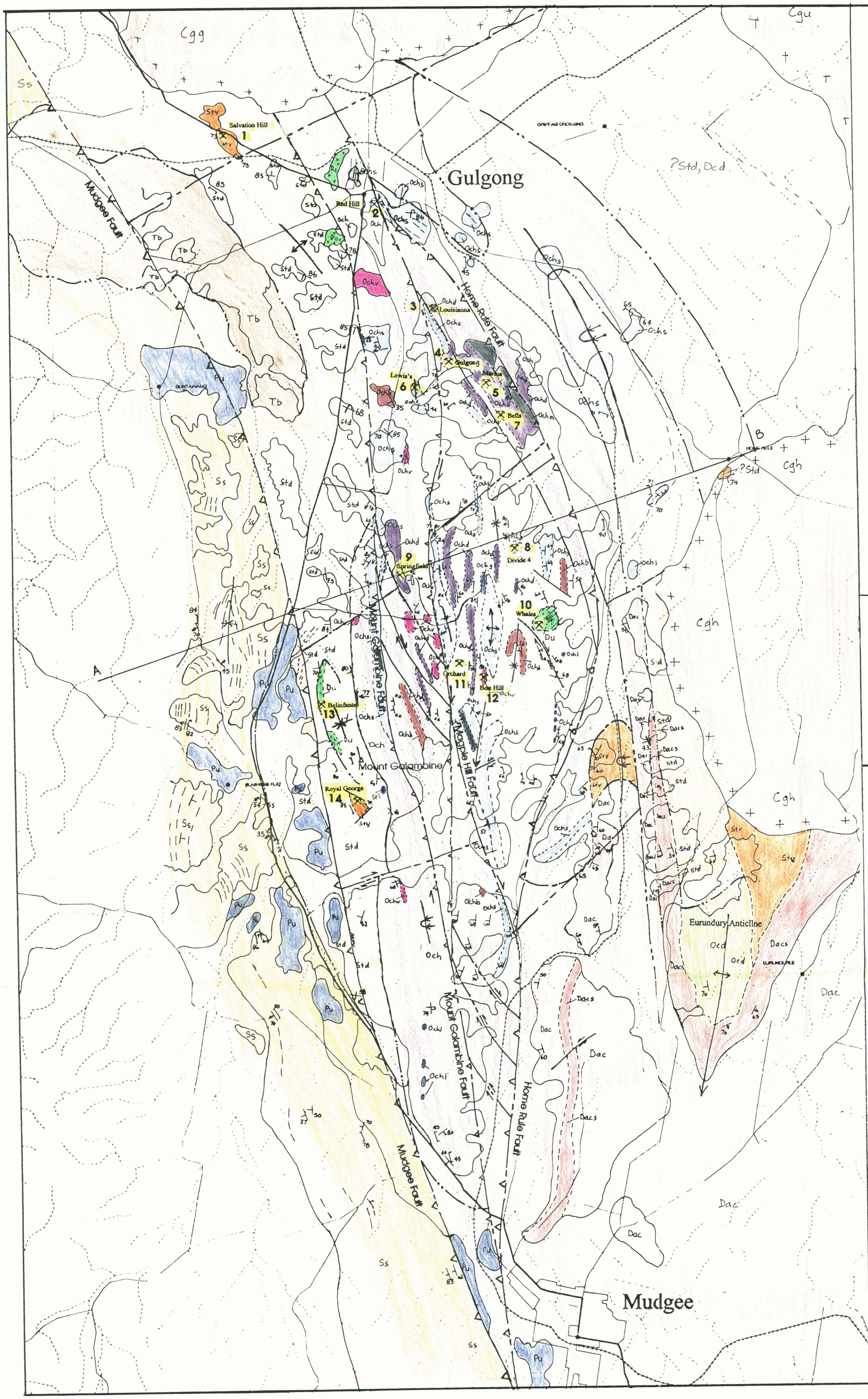


Reference

Early Tertiary
- Tb — Olivine basalt

Early Permian
- Pu — Sandstone, shale, conglomerate

Middle Carboniferous
- Cgg Cgu Cgh — Biotite granite

Early Devonian
- Du — Diorite sills, dykes or small plutons

Carwell Creek Formation
- Dac — Siltstone, shale
- Dacs — Sandstone, siltstone, conglomerate

Middle to Late Silurian

Chesleigh Formation
- Ss — Sandstone, siltstone, shale

Dungaree Volcanics
- Std — Shale, slate, volcaniclastics
- Stv — Lava (rhyolite, rhyodacite)
- Stl — Limestone and limestone breccia

Late Ordovician

Coomber Formation
- Ocd — Lithic sandstone, minor chert

Burranah Formation
- Och — Undifferentiated mafic to intermediate volcanics, volcaniclastics and sediments
- Ochs — Volcaniclastic sandstone and mudstone
- Ochg — Volcaniclastic conglomerate
- Ochb — Volcaniclastic breccia
- Ochm — Mudstone
- Ochv — Lava (latite, shoshonite, absarokite)
- Ochd — Medium to coarse grained monzodiorite
- Ochl — Limestone

- Boundary of 'outcrop' area
- Geological boundary
- Fault
- Fault interpreted from geophysical data
- Geological boundary interpreted from geophysical data
- Zone of shearing
- 40 Strike and dip of strata
- 40 Strike and dip of strata, facing known
- 40 Strike and dip of overturned strata
- 40 Strike and dip of cleavage
- Anticline with plunge of axis
- Syncline with plunge of axis
- Plunge and plunge direction of lineation
- Mineral deposit

N

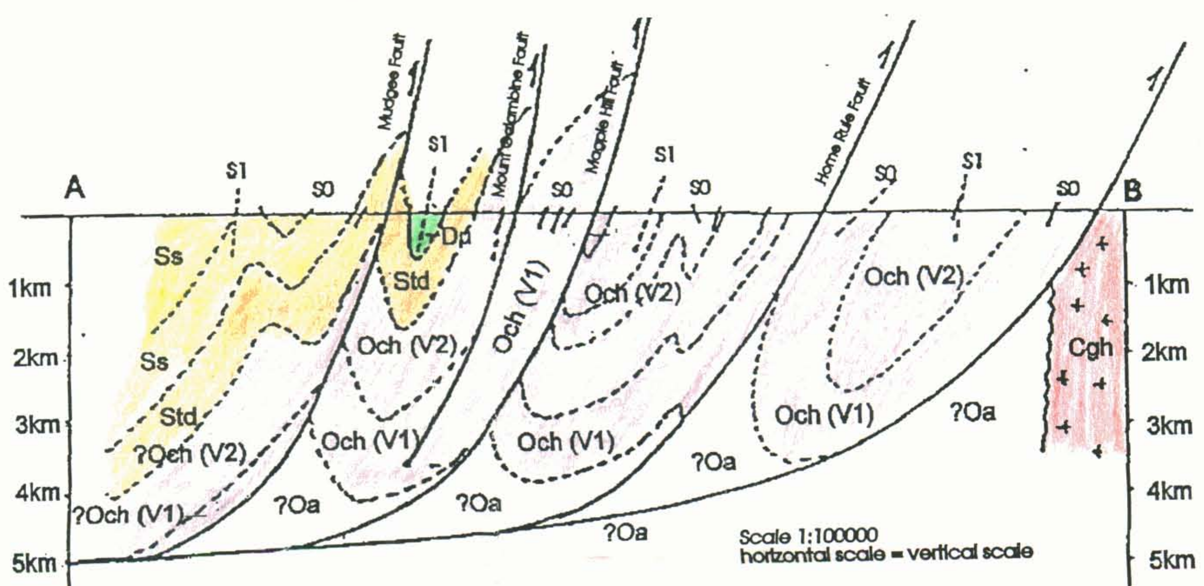
Scale 1:50,000

Kilometres 0 1 2 3 4

Mineral Deposits

Deposit no.	Deposit name	Host formation	Host rock	Commodities
1	Salvation Hill	Dungaree Volcanics	Rhyodacite	Au
2	Red Hill	Ungrouped diorites	Diorite	Au
3	Louisianna	Burranah Formation	Monzodiorite	Au, Cu, Zn
4	Gulgong	Burranah Formation	Monzodiorite	Au, As, Zn
5	Marina	Burranah Formation	Monzodiorite	Au, As, Zn
6	Lewis's	Burranah Formation	Volcaniclastic sandstone	Au, Cu
7	Bells	Burranah Formation	Monzodiorite	Au, Cu, Pb, Zn, Ag, As
8	Divide 4	Burranah Formation	Monzodiorite	Au, As
9	Springfield	Burranah Formation	Monzodiorite	Au, As
10	Whales	Ungrouped diorites	Diorite	Au, Pb, As
11	Orchard	Burranah Formation	Volcaniclastic sandstone	Au, Cu, Pb, Zn, Ag, As
12	Box Hill	Burranah Formation	Latite	Au
13	Belinfante	Ungrouped diorites	Diorite	Au
14	Royal George	Dungaree Volcanics	Rhyodacite	Au

Interpretative Cross Section A-B



- Cgh — Home Rule Granite
- Dm — Diorite
- Ss — Chesleigh Formation
- Std — Dungaree Volcanics

Burranah Formation
- Och (V2) — Magnetic package V2
- Och (V1) — Magnetic package V1

see text for explanation

- Oa — Adaminaby Group

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MUDGEE-GULGONG DISTRICT
PRE QUATERNARY SOLID GEOLOGY INTERPRETATION

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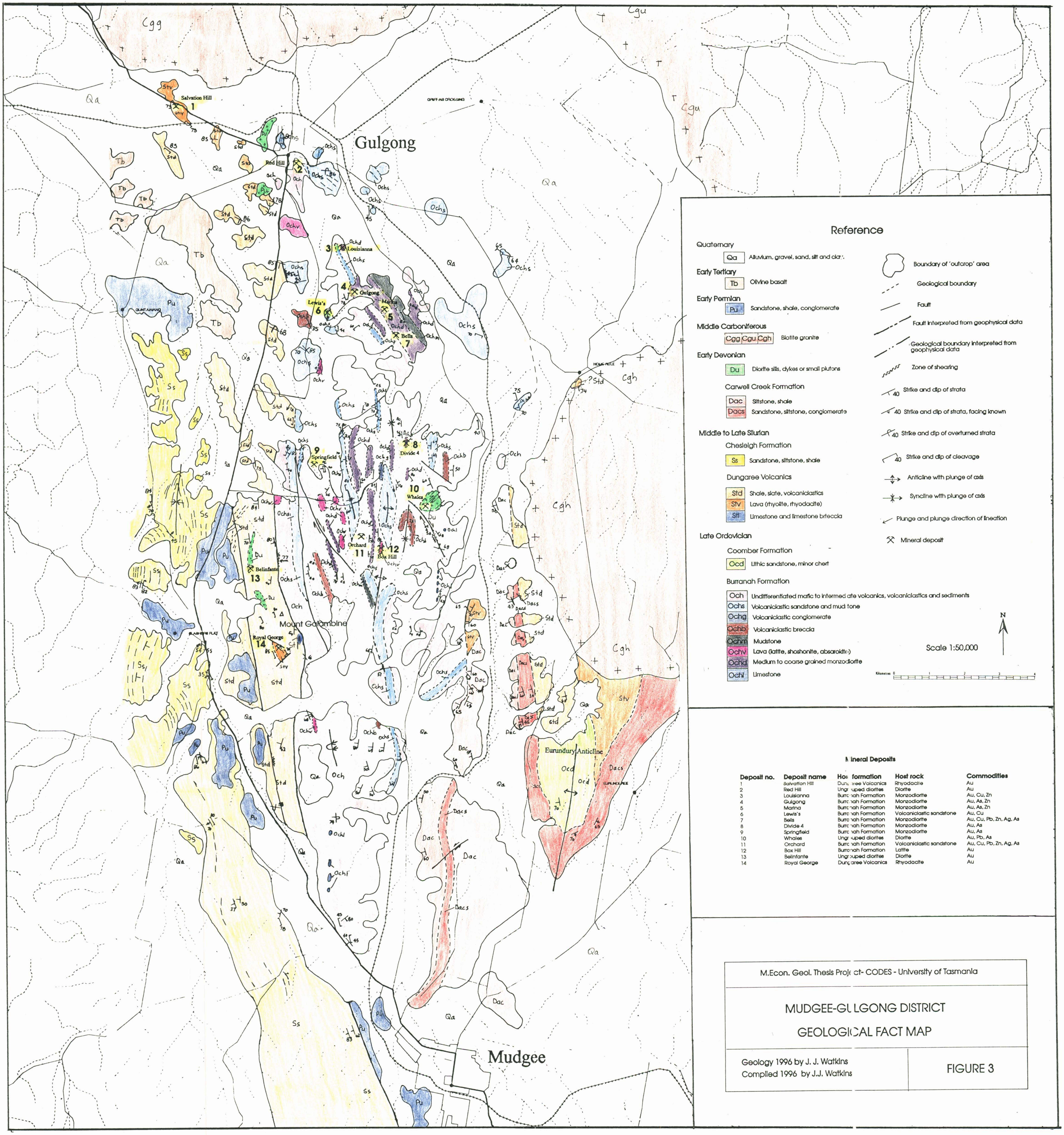
FIGURE 4



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5	Marina	Burranah Formation	Monzodiorite	Au, As, Zn
6	Lewis's	Burranah Formation	Volcaniclastic sandstone	Au, Cu
7	Bells	Burranah Formation	Monzodiorite	Au, Cu, Pb, Zn, Ag, As
8	Divide 4	Burranah Formation	Monzodiorite	Au, As
9	Springfield	Burranah Formation	Monzodiorite	Au, As
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11	Orchard	Burranah Formation	Volcaniclastic sandstone	Au, Cu, Pb, Zn, Ag, As
12	Box Hill	Burranah Formation	Latite	Au
13	Belinfante	Ungrouped diorites	Diorite	Au
14	Royal George	Dungaree Volcanics	Rhyodacite	Au

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MUDGEE-GULGONG DISTRICT

GEOLOGICAL FACT MAP

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FIGURE 3